

# New Electrode Materials for Lithium–Ion Batteries (Review)

T. L. Kulova<sup>z</sup>

Frumkin Institute of Physical Chemistry and Electrochemistry, Russian Academy of Sciences, Moscow, Russia

Received November 8, 2010

**Abstract**—The main principles of operation of modern lithium–ion batteries and the modern trends in development of new–generation batteries are described.

**Keywords:** lithium–ion battery, electrode materials, oxides, silicon, phosphates, vanadium oxides, high–voltage materials

**DOI:** 10.1134/S1023193513010102

## CONTENTS OF REVIEW

1. Introduction. Lithium–ion batteries
  - 1.1. Chemistry of traditional lithium–ion batteries
  - 1.2. Main problems in development of new–generation batteries
2. Negative electrodes
  - 2.1. Oxide–based materials
  - 2.2. Metallic and composite materials
  - 2.3. Silicon–based materials
3. Positive electrodes
  - 3.1. Iron–lithium phosphate
  - 3.2. Vanadium oxide–based materials
  - 3.3. High–voltage materials
4. Conclusion. Main trends in development of new–generation batteries

## 1. INTRODUCTION LITHIUM–ION BATTERIES

### 1.1. Chemistry of Traditional Lithium–Ion Batteries

Lithium–ion batteries (containing no metallic lithium) were developed in Japan in the late eighties–early in the nineties of the previous century [1–3]. Such batteries use as their negative electrodes not metallic lithium or its alloys with other metals, but an intercalation compound of carbon and lithium. Carbon proved to be a very convenient matrix for intercalation of lithium. The specific volume of many carbon graphitized materials changes under intercalation of a rather large amount of lithium by not more than 10% [4].

The potential of carbon electrodes containing a not too high amount of intercalated lithium is 0.5–0.8 V more positive than the potential of a lithium electrode. To reach a sufficiently high battery voltage, the first battery variants used lithiated cobalt oxides as the

active material of the positive electrode. Lithiated cobalt oxide has the potential of about 4 V vs. the lithium electrode, so that the characteristic working battery voltage is 3.5–3.8 V.

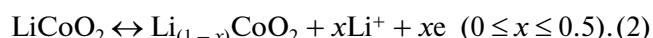
Deintercalation of lithium from the carbon material occurs (on the negative electrode) under discharge of a battery and lithium is intercalated into the oxide (on the positive electrode). Under charging, the processes are reversed. Thus, there is no metallic (zero–valency) lithium in the whole system and the discharge and charging processes are reduced to transport of lithium ions from one electrode to another. It is for this cause that the authors of such a battery introduced the term of “lithium–ion battery” [1]. At the same time, such batteries are often denoted as “rocking chair cells” [5].

In all lithium–ion batteries brought to the marketing stage, the negative electrode is made of carbon materials. The current producing process on the negative electrode is described by the equation:



The direct process corresponds to charging and the reverse process corresponds to battery discharge.

The current-producing process on the positive electrode of the first lithium–ion batteries is described by the following equation:



Apart from lithiated cobalt oxide, lithiated nickel oxide and lithium–manganese spinels are applied in conventional lithium–ion batteries. The processes on such electrodes are similar to the processes on an electrode with lithiated cobalt oxide.

There is extensive review and monograph literature on the conventional lithium–ion batteries [6–13].

Lithium–ion batteries are subject to the regularities common for all battery types. An ideal battery must be absolutely reversible: all charge must be con-

<sup>z</sup> Corresponding author: tkulova@mail.ru (T.L. Kulova).

sumed only in current-producing reactions of charging and discharge (in other words, the current efficiency of these processes must be 100%). In a real battery, there are some other processes (electrochemical and chemical) apart from the current-producing reactions. These side processes (usually irreversible) consume a certain amount of electricity. As a result, the discharge capacity in each cycle proves to be lower than the electricity amount consumed in the previous charging stage. Besides, in the course of cycling, capacity decreases from cycle to cycle. The nature of irreversible processes in batteries of different electrochemical systems is diverse.

Extremely strong oxidants and reducing agents are used in lithium–ion batteries (EMF of such batteries can exceed 4 V and the charging voltage of conventional batteries is always higher than 4.2 V). Therefore, processes of irreversible electrolyte reduction on the negative electrode and its irreversible oxidation of the positive electrode may basically occur in such batteries. Stability of electrolyte towards decomposition (oxidation or reduction) is determined not so much by thermodynamical, as by kinetic factors. In operation of a lithium–ion battery, processes of intercalation of lithium ions into the crystal lattice and their extraction from crystals occur. These processes result in a change in parameters and even the structure of the crystal lattice of active materials and these changes can be both reversible and irreversible. Irreversible changes in the crystal structure of the active materials of the positive and negative electrodes always result in a decrease in intercalation (reversible) capacity.

Particular features of the first cycle are characteristic for lithium–ion batteries. Conventional lithium–ion batteries are assembled from electrodes in the fully discharged state (graphite and LiCoO<sub>2</sub>), so that their cycling always starts from the charging phase. As a rule, the charging capacity exceeds considerably the capacity of the following discharge. For the further cycles, this difference becomes rather low.

The vast majority of lithium–ion batteries is intended for power supply of portable electronic devices (cell phones, notebooks, digital photo and video cameras, wireless tools, etc) and are produced in the form of cells with the capacity of 1 to 10 A h.

### *1.2. Main Problems in Development of New–Generation Batteries*

Modern lithium–ion batteries have the specific energy of 150–200 W h/kg and are superior as regards this indicator to all other battery types, not excepting even silver–zinc ones. Such a high specific energy is one of the determinant factors of rapid development of lithium–ion batteries. Specific energy of a battery is determined by specific capacity of the active substances of the positive and negative electrodes, battery voltage, and design efficiency. The modern specific energy indicators are probably the limit that can be

reached when a conventional electrochemical system is used. So far, an increase in specific energy was reached solely by design improvement. Therefore, one of the important problems in development of new–generation batteries is reduced to finding electrode materials with high capacity.

The cost of the modern lithium–ion batteries is largely determined by the cost of cobalt. While the battery cost plays no particular role when small batteries are used in portable devices, economic considerations become determinant in development of large battery plants (e.g., for electric transport, levelling of peak load etc.).

Finally, the most significant problem in development of new–generation lithium–ion batteries is the safety problem. At present, about 20 cases of ignition or explosions of lithium–ion batteries are registered annually. With account for the multibillion yearly production of such batteries, the probability of accidents is negligible. However, a transition to larger setups makes the safety issue a priority problem.

## 2. NEGATIVE ELECTRODES

Limited specific capacity of carbon materials used in the modern (conventional) lithium–ion batteries and also problems of stability of such materials under cycling induced intensive research directed at searching for alternative negative electrode materials. It is known that many materials are capable of intercalating considerable amounts of lithium at sufficiently negative potentials. Long before application of carbon materials, numerous attempts were made to use aluminum and other metals as a negative electrode matrix. After successful development of the now conventional electrochemical system of lithium–ion batteries (C/LiCoO<sub>2</sub>), the search for an alternative to carbon was continued and it is still in progress. The great diversity of materials studied as regards their application as negative electrodes can be divided as follows: (a) metals and alloys, (b) metal oxides, (c) silicon and silicon–based composites, (d) other materials, including nitrides, phosphides, etc.

### *2.1. Oxide–Based Materials*

Two ways of the functioning of oxide materials as negative electrodes are possible: in some cases, lithium is reversibly intercalated into the crystal lattice of an oxide at not too positive potentials; in other cases, the oxide is first reduced with pure metal formation (in the form of nanosize particles) and lithium oxide, and then lithium is intercalated into this metal; herewith, it is the smallness of metal particles that prevents them from degradation, as the specific volume increases. The most important example of materials operating via the second way is materials based on tin oxides. The first communication on such materials appeared

in 1997 [14] and immediately caused a whole barrage of works in this direction [15–22].

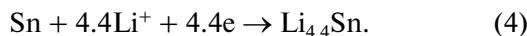
In the initial variant, amorphous mixed oxides with the overall formula of  $\text{SnM}_x\text{O}_y$  (where  $\text{M} = \text{B}, \text{P}, \text{Al}$ ) were considered, e.g., materials with the composition of  $\text{SnB}_{0.56}\text{P}_{0.40}\text{Al}_{0.42}\text{O}_{3.6}$  [15] or  $\text{Sn}_2\text{BPO}_6$  [19]. During the first cathodic polarization of electrode of such a material, tin oxide is reduced forming nanoparticles of metallic tin and boron, phosphorus, and aluminum oxides together with the forming lithium oxide form an amorphous matrix stabilizing tin particles and preventing their coalescence. Simultaneously, lithium interacts with these tin nanoparticles forming alloys with a rather high content of lithium, up to the composition of  $\text{Li}_{4.4}\text{Sn}$ . Due to the smallness of tin particles, alloy formation, though accompanied by a significant increase in the specific volume, still results in no appearance of such high internal stress, as would cause destruction of metal particles. In the further cycling, lithium interacts reversibly with tin particles, while the oxide matrix undergoes practically no changes.

The main advantage of tin–oxide electrodes as compared to carbon electrodes consists in their enhanced specific capacity. The composition of  $\text{Li}_{4.4}\text{Sn}$  corresponds to specific capacity of 991 mA h/g and 7234 mA h/cm<sup>3</sup> as per tin mass and volume, accordingly.

The above mechanism of functioning of oxide–tin electrodes was experimentally confirmed in [15–17]. Herewith, according to the data of [15–17], the whole charge during the first cathodic polarization is consumed only in reduction of tin oxide:



and also in formation of an alloy of lithium and tin:



The charge corresponding to processes (3a) and (3b) corresponds to irreversible capacity of the first cycle, while that corresponding to process (4) represents reversible capacity. As follows from equations (3) and (4), irreversible capacity of the first cycle for  $\text{SnO}_2$ -based electrodes approximately corresponds to theoretical reversible capacity. This circumstance is a significant fault of such electrodes. Another fault is that their practical capacity is usually below the theoretical values. As a rule, the initial capacity of electrodes based on tin oxides is 300 to 600 mA h/g and decreases nearly by half in the first 10–30 cycles.

Such strong degradation was explained by gradual recrystallization and agglomeration of tin particles [15, 16, 19]. Despite this, works on improvement of negative electrodes based on tin oxides are still in progress [23–59]. Herewith, main attention is paid to development of such synthesis techniques as would provide stability of the oxide nanostructure and metallic tin formed as a result of their reduction.

A certain improvement in stability under cycling was achieved, in particular, by the doping of tin dioxide by molybdenum [24] and also by application of mesotubes of tin dioxide [27].

At the example of materials based on tin dioxide, advantages of thin-film electrodes were shown regarding considerably higher stability under cycling than that of electrodes with a relatively thick active layer [18, 20–21, 23, 29, 32–38, 41, 42]. Such films were manufactured using various methods, including magnetron deposition [32].

High hopes were placed on various composites of tin oxides with other materials, primarily, with carbon-based materials [47–59], including carbon nanotubes [48, 51, 55]. Other suggestions of interest are composites or mixed tin oxides with other oxides, e.g., with magnesium oxide [60], silicon oxides [61–63], cobalt oxide [64], zinc oxide [65]. In the two latter cases, the point at issue is not composites, but rather spinel-type  $\text{Co}_2\text{SnO}_4$  and  $\text{Zn}_2\text{SnO}_4$  compounds. In the case of polarization of such compounds, rather high capacity (about 1 A h/g) is implemented in the range of potentials of 0 to 3 V, which is unacceptable for the negative electrode. Capacity released at the potentials of 0 to 1 V does not exceed 300 mA h/g, so that such materials have no advantages before graphite. The same remark also refers to the composite of tin dioxide with antimony [66].

The first description of oxides, with which lithium reversibly interacts without formation of an alloy of lithium with the reduced metal, appeared in 2000 at the example of oxides of bivalent cobalt, copper, nickel, and iron [67]. In this case, lithium oxide formed in the cathodic process is capable of regenerating in the anodic process, so that the reaction of bivalent metal oxide with lithium proves to be reversible:



(as opposed to irreversible reaction (1)). Thus, it would seem that the source of irreversible capacity characteristics of materials based on tin oxides disappears, while reversible capacity is preserved at 600–700 mA h/g. The possibility of reversible occurrence of process (5) was substantiated thermodynamically and confirmed experimentally in many works [68–71]. However, the anodic process (metal oxidation and formation of lithium ions) occurs at a relatively high potential (about 2 V), which considerably lowers the value of such materials. Nevertheless, the works on using metal oxides in negative electrodes are still continued [72–96]. An invariable condition of reversible occurrence of process (3) is preservation of the active material in a nanostructured form [69]. The aim of the majority of studies is precisely the development of stable nanostructured oxides. As examples, one could name such materials of  $\text{CuO}$  as nanobands [75], nanotubes [76], nanospheres in the form of dandelions [77, 79], nanorods [78], nanowires [87]. Also,  $\text{NiO}$  nanotubes [85],  $\text{Cu}_2\text{O}$  nanoglobules [90],  $\text{ZnO}$  nano-

rods [91] are described. One of the factors nanostructure stabilization is using composites of oxides and other materials, primarily, with carbon, including carbon nanotubes [83] and nanospheres [94, 95] or metallic nanoparticles [91]. Another approach is using continuous solid [80–82, 84–86, 96] or skeleton [88, 90] oxide films. (It is pointed out in [80] that application of an additional surface film of MgO on a thin NiO film promotes improvement of cyclability at high current loads).

Though the functioning of oxide electrodes without formation of lithium alloys with the corresponding metals is not accompanied by consumption of irreversible capacity in reduction of these metals, irreversible capacity related to reduction of electrolyte and formation of SEI is still preserved [69, 71] and in this respect, oxide negative electrodes are quite similar to electrodes of carbon materials.

Apart from oxides of bivalent metals described above, much attention has lately been paid to trivalent iron oxides ( $\text{Fe}_2\text{O}_3$ ) and cobalt oxide (II, III) ( $\text{Co}_3\text{O}_4$ ) that function according to a similar mechanism [97–130]. In this case, various nanostructures (nanospheres [99, 101, 108, 110, 111, 126], nanopyrramids [104], nanoplates [98, 112, 124], nanowires [115, 125], nanotubes [113, 114], nanoneedles [116, 117], nanorods [118, 122]), thin films [100, 107, 119–121], and nanocomposites with carbon [102, 103, 106, 109, 123, 127] have also gained the widest acceptance. Similar properties are also characteristic of mixed spinel-type compounds:  $\text{CuCo}_2\text{O}_4$  [131],  $\text{CoFe}_2\text{O}_4$  and  $\text{NiFe}_2\text{O}_4$  [132–134],  $\text{NiCo}_2\text{O}_4$  [135],  $\text{ZnCo}_2\text{O}_4$  [136].

However, as opposed to the above described oxides, chromium oxide, though capable of functioning in the same way (i.e., without irreversible formation of metallic chromium), features in practice rather moderate capacity, which is related to high electron resistance of such a material [137]. To overcome this fault, it was suggested to use  $\text{Cr}_2\text{O}_3$  in the form of a mesoporous electrode [138]. On the whole, this attempt proved to be unsuccessful, but this paper presents very demonstrative data on formation of polymer products of electrolyte reduction, i.e., data on irreversible capacity of the oxide electrode.

Also attempts have been made lately to use oxides of other metals as the active material of the negative electrode. In all cases, the studied objects were nanomaterials, such as  $\text{Mn}_3\text{O}_4$  nanofibers [139], thin films of nanocrystalline  $\text{MnO}$  [140], nanofiber composites of  $\text{MnO}_x$  with carbon [141], dendritic  $\text{MoO}_2$  nanostructures [142],  $\text{MoO}_3$  nanopowders [143, 144]. However, all the studied variants demonstrated no advantages, as compared to cobalt, copper, nickel, and iron oxides: in all cases, capacity obtained in the potential range of 0 to 1.5 V did not exceed capacity of usual carbon-based electrodes.

Of greatest interest are the recent works, in which stabilization of the cobalt oxide nanostructure was

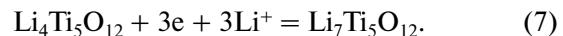
achieved through its “fixation” on the surface of a virus [145, 146]. Though very high specific capacity values could not be obtained in the first experiments, nanostructure stabilization was confirmed and the possibility of operation of such electrodes under forced modes was demonstrated. Similarly, positive electrodes were manufactured using viruses and iron-lithium phosphate [147].

A variety of works is dedicated to attempts of using titanium oxides as negative electrodes (see, e.g., the review in [148]). Lithium is reversibly intercalated into titanium oxide forming a variable composition phase:



Intercalation of a single mol of lithium per mol of titanium dioxide corresponds to specific capacity of 335 mA h/g, i.e., lower than in the case of using graphite, so that the interest of researchers to titanium dioxide is somewhat surprising. As well known, titanium dioxide exists in several crystallographic modifications: rutile, anatase, brookite, and also in the bronze structure. And practically all of these were studied with respect to lithium intercalation. In all cases, this process is described by equation (6), but the shape of discharge curves is diverse: when lithium is intercalated into rutile, the potential changes smoothly in the range of 2.5 to 1 V [149–152], while in the case of intercalation into anatase, the curves manifest a practically horizontal plateau at the potential of about 2 V [149–159]. More or less horizontal plateaus are also registered on electrodes of brookite [160, 161] and  $\text{TiO}_2$  with a bronze structure [162]. Such high working potential values result in a decrease in the voltage of batteries with conventional positive electrodes (some researchers see this not as a fault, but as an advantage: enhanced safety of lithium-ion batteries). In the vast majority of cases, titanium dioxide is used in the form of nanomaterials (nanotubes [155, 163–169], nanorods [156, 170], hollow nanospheres [171, 172], nanowires [173], nanoflakes [159]), which is particularly due to its low electron conductivity, and also in the form of composites with carbon [167, 174], tin [165, 169, 175], silver [168], silicon [176], and thin films [177, 178].

A much more important negative electrode material than titanium dioxide is considered to be lithium titanate  $\text{Li}_4\text{Ti}_5\text{O}_{12}$  [179–181]. A single formula unit of this substance can accept three lithium ions; therefore, the theoretical specific capacitance of this process is 175 mA h/g. The reversible electrochemical process is described by the following reaction:



As a result of this reaction, the initial spinel structure of  $\text{Li}_4\text{Ti}_5\text{O}_{12}$  passes into the compounds of  $\text{Li}_7\text{Ti}_5\text{O}_{12}$  with a NaCl-type structure [182]. Thus, as opposed to the majority of other electrode materials, in which the potential depends on the degree of discharge of the material (coefficient  $x$  in the active substance formula,

e.g.,  $\text{Li}_x\text{C}_6$ ), in this case, the two-phase equilibrium of  $(\text{Li}_4\text{Ti}_5\text{O}_{12})_{\text{spinel}}/(\text{Li}_7\text{Ti}_5\text{O}_{12})_{\text{quasi-NaCl}}$  is always preserved and the potential remains constant (horizontal plateaus are registered in the discharge and charging curves [182, 183]). According to the data of many authors, this equilibrium potential is 1.55 V vs. metallic lithium. There is another important circumstance: practically no volume variation occurs under lithiation, i.e., under transition from the  $\text{Li}_4\text{Ti}_5\text{O}_{12}$  phase to the  $\text{Li}_7\text{Ti}_5\text{O}_{12}$  phase (the specific volume changes less than by 0.1%, while even lithiation of graphite results in a volume change by 10–12%). Thus, mechanical degradation of the structure is eliminated and very high structure stability under cycling is provided. The most significant fault of lithium titanate as an active material is its low electron conductivity. Therefore, the greatest efforts were directed at development of doped materials [184–200], composites with electron-conducting additives [201–203], materials with coatings [204–206] and nanomaterials [207–210].

In conclusion of this section, one must mention the cycle of works of [211–215], in which the promising character of thin-film negative electrodes based on mixed tin and titanium oxides (with  $\text{TiO}_2$  content of about 10%) is shown. In such electrodes, tin oxide is in the form of nanostructured units and their cycling does not result in irreversible process (3b) and ultimately the process similar to reaction (5) is implemented.

## 2.2. Metallic and Composite Materials

As already pointed out, repeated attempts of using aluminum and other metals as a matrix for intercalation of lithium were made in the early period of works on lithium batteries (before appearance of lithium-ion batteries with graphite-based negative electrodes). In the meantime, the main problem of an immense increase in the specific volume under lithium intercalation resulting in destruction of the metallic matrix was identified. Stability of the electrode to such destruction is enhanced at a decrease in the characteristic size of the metal particle and especially at a transition to nanosize objects [216]. It is for stabilization of nanosize tin particles that the approach of reduction of tin oxides or the corresponding glasses was used [14]. Other approaches to stabilization of nanosize particles are also described. Herewith, tin remained the most attractive metal for lithium insertion. Tin can form intermetallic compounds with lithium; besides, the intermetallide with the highest lithium content has the composition of  $\text{Li}_{22}\text{Sn}_5$  ( $\text{Li}_{4.4}\text{Sn}$ ). This composition corresponds to specific capacity of 790 mA h/g or 2023 mA h/cm<sup>3</sup>. The density of metallic tin is 7.29 g/cm<sup>3</sup>, the density of  $\text{Li}_{22}\text{Sn}_5$  is 2.56 g/cm<sup>3</sup>. Thus, the specific volume increases 2.85-fold at a transition from tin to  $\text{Li}_{22}\text{Sn}_5$ .

No ultradispersed tin powders can be manufactured. Electrodes made of the finest particles have the

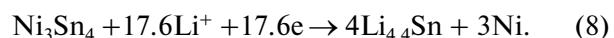
initial capacity of about 500 mA h/g, but particle agglomeration occurs under cycling and already by the tenth cycle, capacity does not exceed 150 mA h/g. Powders manufactured using special methods and containing a certain amount of oxides function in the same way, as described in Section 2.1., and capacity of about 300 mA h/g can also be obtained on such electrodes after the 100-th cycle [217–221]. In [222], electrodes containing tin nanowhiskers are described. Such electrodes were steadily cycled with the capacity of about 400 mA h/g, but the anodic process in this case occurred in the potential range of 0.6–0.7 V.

The attempts of manufacturing electrodes with thin tin films proved to be more successful [223–234]. Herewith, the best results were obtained in the case of using two-phase Sn-Al films [224], application of thin tin films on copper nanowhiskers [226] and titanium dioxide nanowhiskers [233] or copper nanofoam [227], and also manufacturing of porous tin oxides [228, 229].

The most reliable stabilization of tin nanostructure is provided by using alloys and composites. Herewith, a clear boundary between these objects is not always easily drawn. Of the binary systems, the greatest acceptance was gained by the systems of tin–copper [235–250], tin–nickel [251–269], tin–cobalt [267, 269–277], and tin–antimony [278–290].

The intermetallic  $\text{Cu}_6\text{Sn}_5$  compound can reversibly absorb up to 13 lithium atoms per formula unit; the theoretical capacity of intercalation compound  $\text{Li}_{13}\text{Cu}_6\text{Sn}_5$  is 358 mA h/g, which is comparable to capacity of graphite electrodes. And despite this, studies of the tin–copper system are still in progress. Certain advantages are characteristic of thin-film electrodes of the Sn/ $\text{Cu}_6\text{Sn}_5$  composite described in [238]. These were cycled with capacity of more than 400 mA h/g. However, in this case, lithium intercalation occurred at the potentials of 0.1–0.3 V and its anodic extraction took place at the potentials of 0.5–0.7 V. The best characteristics were typical for electrodes of  $\text{Cu}_6\text{Sn}_5$  applied on a porous copper support. The initial capacity of such electrodes was above 490 mA h/g and after 20 cycles, it was at least 400 mA h/g [248].

A binary tin–nickel system contains the  $\text{Ni}_3\text{Sn}$ ,  $\text{Ni}_3\text{Sn}_2$ , and  $\text{Ni}_3\text{Sn}_4$  intermetallides, of which the latter is most often mentioned in the literature. The mechanism of reversible lithium intercalation into tin–nickel alloys differs from the mechanism of its intercalation into tin–copper alloys. It is assumed that decomposition of the intermetallide occurs under lithiation, a lithium–copper alloy is formed and the nickel phase is separated [252, 254, 257]:



The theoretical specific capacity corresponding to this process is 725 mA h/g. In fact, the values of 100 to 300 mA h/g were obtained in the majority of works, though there are more optimistic results, e.g., in [253], the capacity of 650 mA h/g was obtained on a thin

alloy film with the tin content of 62 at %, i.e., in a system containing intermetallide  $\text{Ni}_3\text{Sn}_4$  and pure tin. In [257], the data on capacitance of about 500 mA h/g at the 10th cycle and 350 mA h/g at the 50-th cycle are given. In [258], capacity of 500 mA h/g after 200 cycles for application of  $\text{NiSn}$  on copper nanowiskers was reported. The anodic process of lithium extraction occurs at the potentials of about 0.5 V.

The Sn–Co system has no significant advantages before the Sn–Ni system. The best results were obtained not with pure Sn–Co alloys, but with the  $\text{CoSn}_2/\text{Sn}$  composite [273] similar to a certain degree to the  $\text{Sn}/\text{Cu}_6\text{Sn}_5$  composite.

The tin–antimony alloy appears to be better matrix for reversible lithium intercalation than pure antimony. The Sn/SnSb composite is most often used [278, 282]. Decomposition of intermetallide and formation of separate phases of lithium alloys with antimony and tin occurs under lithium intercalation into the tin–antimony alloy (this system forms only a single stable intermetallide of  $\text{SnSb}$ ) [279, 280]:



More or less pronounced plateaus corresponding to separate stages of this process are registered in the charging and discharge curves. Herewith, anodic extraction of the larger amount of lithium occurs at the potentials of 0.6 to 1.0 V. The overall reversible capacity can reach 600 mA h/g.

Of the other tin-containing binary alloys, the systems of tin–iron [291, 292], tin–zinc [293], tin–calcium [294], tin–magnesium [295], tin–cerium [296] were reported. They are of no particular interest. Of similarly little success was application of three-component alloys, such as Sn–Sb–Ag [283, 297, 298], Sn–Cu–Co [299, 300], Sn–Sb–Ni [301], Sn–Ni–La [302], Sn–Cu–Zn [300, 303], Sn–Cu–Ni [300], Sn–Cu–Fe [300], Sn–Fe–Ag [304], Sn–Sb–Cu [305], and Sn–Sb–Co [306].

High hopes were (and are) put on composites of metals and carbon; herewith, special place is given to carbon nanostructures. Quite diverse composites were suggested and studied, of which tin composites and its alloys (with cobalt, iron, nickel, germanium, silver, antimony) and carbon can be considered the most important variants [307–340].

Despite the great diversity of the studied metal composites with carbon, on the whole, the characteristics of such materials have no advantages as compared to the conventional graphite materials. Only in several works (see, e.g., [313, 316, 318, 335]), specific capacitance somewhat exceeding 400 mA h/g was obtained. Herewith, the best studied systems are Sn–Co–C [323, 326–329, 331, 335–337], on which the best results were obtained. (One should once more point out that many works report much higher specific capacity values, but they are implemented in the

potential ranges of 0 to 2.5 or even to 3 V, which is absolutely unacceptable for negative electrodes of lithium–ion batteries).

### 2.3. Silicon–Based Materials

It is known that silicon features the all-time high capacity of reversible lithium insertion (alloy formation). In the phase diagram of silicon–lithium, the intermetallide with the highest lithium content has the composition of  $\text{Li}_{4.4}\text{Si}$  ( $\text{Li}_{22}\text{Si}_5$ ), which corresponds to specific capacity of 4200 mA h/g [341–345]. (One should point out that these indicator corresponds to specific capacity of silicon in the course of formation of an alloy with lithium, i.e., in the course of battery charging; in the reverse process, i.e., under extraction of lithium from the  $\text{Li}_{4.4}\text{Si}$  intermetallide, specific capacity of the intermetallide is about 2000 mA h/g).

However, the known great increase in the specific volume of solid crystalline silicon under insertion of a sufficiently high amount of lithium was considered to be an insurmountable obstacle for application of this material as the active substance of negative electrodes [345–349]. Communications in the end of the twentieth century as to stability of silicon–based nanostructured materials towards mechanical fracture under repeated electrochemical insertion of lithium from conventional aprotic solvents caused, if not a revolution, then a sensation in the research world and results in a literal burst of studies on silicon electrodes. At first, the most impressive results were obtained on samples with thin films of amorphous silicon [348, 350–359]. In [350], the data on cycling are presented for electrodes with an amorphous silicon film with the thickness of 50 nm for 100 cycles at specific capacity of 3500 mA h/g; in [352], more than 1000 cycles with capacity of 1500 mA h/g were obtained on an amorphous silicon film with the thickness of 77 nm; in [353], capacity of 2000 mA h/g obtained for 180 cycles on a film with the thickness of 300 nm was already reported. It was found even at that time that stability of amorphous silicon films towards cycling decreases considerably at an increase in the film thickness. Thus, 1000 cycles with capacity above 3000 mA h/g were obtained on films with the thickness of 50 nm, while 200 cycles with capacity of 2500 mA h/g were obtained on a film with the thickness of 150 nm [356]. In the case of films with the thickness of 340 nm, 450 cycles with capacity of 2000 mA h/g were obtained while 50 cycles with the same capacity were obtained for a film with the thickness of 3.6  $\mu\text{m}$  [358].

It was found that the most important causes of degradation of thin-film electrodes are the actual film disintegration (at first, intergranular ohmic resistance grow drastically and then the film is transformed into powder) and mainly insufficient film adhesion to the support. Herewith, it was confirmed that adhesion to the support very strongly depends on the conditions of its surface treatment [352, 360–372]. One should

point out that the process of desintegration of the material is at least in part of dynamic character: lithium insertion–extraction results in agglomeration of silicon particles resulting in a decrease in reversible capacity [345, 362].

Though the data on thin-film electrode of amorphous silicon in the literature are not contradictory, the quantitative difference in these data is rather large. The difference in the experimental data is at least in part related to the nature and method of preparation of the support surface, the method of application of thin films, conditions of electrochemical studies. The most wide-spread method of application of thin amorphous silicon films is probably magnetron deposition (in most cases, radio-frequency) [354, 360–362, 367, 369, 371, 373, 374]. Vacuum deposition using a doped silicon target was used, in particular, in [352, 353, 356, 358, 359, 370, 375]. Certain acceptance was gained by the method of chemical vacuum deposition due to decomposition of silanes ( $\text{SiH}_4$  and  $\text{Si}_2\text{H}_6$ ) [348, 350, 376–381], electron-beam deposition method [368], physical deposition technique [382], pulsed laser deposition technique.

Many authors point out that electrochemical behavior of thin-film electrodes of amorphous silicon depends on the nature of electrolyte. 1 M  $\text{LiPF}_6$  in a mixture of ethylene carbonate with dimethyl carbonate still remains the most popular solution [348, 354, 360, 361, 367, 368, 369, 382, 383]. The cause for this is possibly trivial: the electrolyte applied is the validated electrolyte used in commercial lithium-ion batteries with carbon positive electrodes. Nevertheless, there are works on alternative electrolytes, particularly, with 1 M  $\text{LiClO}_4$  solution in propylene carbonate [350, 353, 356, 358, 370] and even in ionic liquids [372] and in solutions of lithium bisoxolate borate [384].

Thin films of amorphous silicon are, while not the only ones, still the best studied pure silicon samples. However, attempts were made to use just dispersed silicon in the form of a conventional active material. It was clear herewith that the characteristic size of silicon particles had to be submicron. It was found that partial lithiation of crystalline silicon and then its amorphization occur already under the initial cathodic polarization [372, 385]. All such electrodes are destroyed and can indeed be cycled only to a small depth. In any case, desintegration of silicon particles results in appearance of large internal ohmic resistance decreasing the characteristics of the electrode [386].

Somewhat greater attention was paid to electrodes in which dispersed silicon is mixed with an active or inactive binder. A usual binder is, as well known, polyvinylidene fluoride (PVdF) (see, e.g., [387, 388]). At the same time, PVdF cannot elongate very much, so that it can hardly sustain large volume variations of silicon under lithium intercalation. It is for this cause that a number of authors studied other binders capable of compensating volume variations of silicon under insertion of lithium. The following binders were sug-

gested among others: polyethylene oxide with lithium perchlorate (PEO– $\text{LiClO}_4$ ) and polyethylene glycol with lithium perchlorate (PEG– $\text{LiClO}_4$ ) [389]; however, no real success was obtained. Somewhat better results were obtained when PVdF was replaced by a mixture of styrene–butadiene rubber with the sodium salt of carboxymethyl cellulose; this mixture is characterized by a somewhat greater elastic elongation [390]. Carboxymethyl cellulose (in the form of a sodium salt) also turned out to be a good binder [391–393]. Finally, one should mention polyamide imide. It turned out that its use as a binder for dispersed silicon has considerable advantages as compared to PVdF [394].

Anyway, using simple dispersed silicon even with better binders is a certain palliative. In the best one of the above works, [394], specific capacitance of about 2000 mA h/g for 20 cycles was obtained.

Most recently, interesting communications appeared as to synthesis of silicon nanowhiskers and the possibility of their application in lithium-ion batteries [395–399]. Unfortunately, the works of this research group received no documentary evidence; besides, only the data on a limited number of cycles are presented (about 50). But the idea of obtaining silicon in the form of whiskers deserves attention. Of special interest is the suggestion to develop whiskers in the form of a core–shell system [399]. Here, the crystalline core provides mechanical strength and conductivity of the whisker and the amorphous shell is the main component for reversible lithium intercalation.

A more cardinal method of developing stable silicon nanoparticles (amorphous particles) is synthesis of silicon composites with other materials, of which the most important is carbon. It was found already in the first works that the trivial mixing of dispersed components (silicon and carbon), even when high energy grinding was used (mechanical activation), does not result in obtaining high-capacity, steadily operating electrodes. A prerequisite was the sufficiently high content of low-active carbon (up to 60%), so that the theoretical capacity of silicon in such composites was completely lost [400–410].

The natural way was to prepare silicon composites with carbon using various synthetic techniques, including the methods of decomposition of carbon and/or silicon compounds. Most recently, development of composites of nanosilicon with carbon nanotubes has gained certain acceptance [411–415]. This popularity is not well justified. Carbon nanotubes as such (both single-wall and multiwall) have no advantages as compared to other carbon materials; their intercalation capacity is considerably lower than the theoretical value, which is quite understandable. References in some papers regarding increased intercalation capacity usually do not separate reversible and irreversible capacity [416–438]. Besides, in most cases, increased values of intercalation capacity of carbon nanotubes were not confirmed in the further works. One of the arguments for introduction of car-

bon nanotubes into composites with silicon were good mechanical properties of nanotubes that could provide sufficient compensation of volume changes under cycling. Another possible property of carbon nanotubes is their increased electron conductivity. But in all cases, characteristics of silicon composites with carbon nanotubes did not exceed half the theoretical capacity.

It appears more attractive to manufacture nanostructured composites of silicon with carbon of different methods of decomposition of organic and/or silicon-containing compounds. Most often, pyrolytic decomposition of the corresponding precursors is used (see, e.g., [439–465]). Among other methods, one should mention thermal vacuum deposition (TVD) [466–468], chemical vacuum deposition (CVD) [469–477]. One must also mention the attempts of developing composites of carbon and silicon whiskers [478]. Finally, the original method of developing thin-film electrodes of silicon–carbon composites using alternated magnetron deposition of very thin (with the thickness below 20 nm) silicon layers and graphite is described in [479–481].

If the composites of silicon with carbon can be considered as the most promising direction of development of silicon-based negative electrodes (or, in any cases, as the most realistic option for development of electrodes with relatively thick active layers), then various composites of silicon with other materials are rather exotic. Among such composites one should mention composites of silicon with silver (its main aim was to increase electron density) [482–486], with nickel [487–491], iron [489, 492–494], copper [495–497], and many other components [498–509].

Literature on irreversible processes on silicon-based electrodes is much sparser than the literature on irreversible processes on carbon electrodes and is largely fragmented. All researchers point out that at least partially irreversible processes under initial cathodic polarization of silicon electrodes are reduced to formation of SEI. Herewith, it is clear that the conditions of SEI formation (or conditions for reduction of components of electrolyte) on silicon differ from the corresponding conditions on carbon. Reduction of electrolyte on silicon occurs at much more negative potentials than on carbon, usually at the potentials to the negative of 0.6 V (see, e.g., [382]). It is known that the surface of silicon is initially always coated by a certain native film which can contain both oxide groups ( $\text{Si}=\text{O}-\text{Si}$ ) and silanol  $\text{Si}-\text{OH}$  [384]. Such groups in themselves can be reduced with formation of SEI, which provides a certain contribution to irreversible capacity. The native film is replaced by SEI characteristic for such conditions practically already in the first cycles. Naturally, the conditions of SEI formation on silicon depend on the composition of electrolyte. In the simplest case, SEI consists of organic and inorganic salts ( $\text{Li}_2\text{CO}_3$ ,  $\text{LiF}$ ,  $\text{LiOCOOR}$ ) and polyethylene oxide-type materials [397]. SEI on silicon has a

dynamic character (same as in carbon) and its structure changes under cycling [395]. A significant improvement of SEI (and accordingly a decrease in irreversible capacity) can be achieved by introduction of various additives into electrolyte or silicon-based composite [509].

### 3. POSITIVE ELECTRODES

#### 3.1. Iron–Lithium Phosphate

As already mentioned, lithiated cobalt and nickel oxides and also lithium–manganese spinels are used as the active material in conventional lithium–ion batteries. All these materials belong to the 4 V grade, i.e., their potential is 3.5–4.0 V under discharge and 3.7 to 4.3 V under charging.

As all conventional positive electrode materials are designed for the charging at relatively high positive potentials, these materials pose certain problems regarding operational safety of lithium–ion batteries. It is for this cause that attention has been lately paid to search for materials that would operate at somewhat less positive potentials. The most probable variant of replacement of conventional materials is considered to be lithiated iron phosphate that has already reached the commercialization stage.

The possibility of using  $\text{LiFePO}_4$  (triphylite) as the active material of the positive electrodes was first mentioned in 1997 [510], i.e., even before commercialization of lithium–ion batteries in their modern form. The main merits and faults of materials with an olivine structure were elucidated already in the earliest publications. The  $\text{FePO}_4$  phase is formed in cathodic extraction of lithium from  $\text{LiFePO}_4$ , so that only the ratio of the amounts of  $\text{LiFePO}_4$  and  $\text{FePO}_4$  phases is changed in the course of charging (in the anodic process) and discharge (in the cathodic process) and the process occurs at a practically constant potential [511] and is not complicated by Jahn–Teller distortions.  $\text{LiFePO}_4$  favorably compares with the conventional materials of positive electrodes due to its lower cost and insignificant toxicity. At the same time, electron conductivity of  $\text{LiFePO}_4$  is very small:  $10^{-9}$  S/cm [512]. In [510], in discharge even at the current density of 2 mA/g (i.e., approximately, in the C/80 mode), discharge capacity of 100–110 mA h/g was obtained, which corresponds to about 60% of the theoretical value.

To solve the problem of low conductivity of  $\text{LiFePO}_4$ , several approaches were suggested, including a decrease in the size of  $\text{LiFePO}_4$  particles and their uniform size distribution [513, 514]; coating of  $\text{LiFePO}_4$  particles by a conducting material, most often, carbon [515–519], synthesis of  $\text{LiFePO}_4$  composites with a conducting additive (particularly, carbon), in which each  $\text{LiFePO}_4$  particle would be coated by a thin layer of such an additive [520–522], development of special morphology and texture of  $\text{LiFePO}_4$

particles [523], and also selective doping of LiFePO<sub>4</sub> by multivalent cations [524–526]. The most popular approach is development of the material in the form of very fine particles with an uniform coating by carbon with the thickness of several nanometers.

The equilibrium potential of the LiFePO<sub>4</sub>/FePO<sub>4</sub> system is about 3.5 V vs. the lithium electrode, i.e., it is considerably lower than in the case of conventional positive electrode materials. This simplifies substantially the problem of oxidative degradation of electrolyte and enhances the safety of batteries. It is shown in [527] that in the series of phosphates Li<sub>3</sub>Fe<sub>2</sub>(PO<sub>4</sub>)<sub>3</sub>, LiFeP<sub>2</sub>O<sub>7</sub>, Fe<sub>4</sub>(P<sub>2</sub>O<sub>7</sub>)<sub>3</sub>, and LiFePO<sub>4</sub>, the position of the level of the Fe<sup>3+</sup>/Fe<sup>2+</sup> redox couple in the latter differs most from the Fermi level of lithium (accordingly, 2.8, 2.9, 3.1, and 3.5 eV), which determines the advantages of this compound.

Fine reversibility is of due to the practically similar structure of LiFePO<sub>4</sub> and FePO<sub>4</sub>. Crystallographic parameters *a*, *b*, and *c* are, accordingly, 0.6008, 1.0334, and 0.4693 nm for LiFePO<sub>4</sub> and 0.5792, 0.9821, and 0.4788 nm for FePO<sub>4</sub> [528].

Under charging, i.e., anodic delithiation of LiFePO<sub>4</sub> grains, the product, FePO<sub>4</sub>, is formed on the surface. In the course of charging, the core of LiFePO<sub>4</sub> decreases, the FePO<sub>4</sub> shell increases and the surface area of the interface decreases, which results in an increase in true current density. As a result, lithium cannot be fully extracted at this current. The authors of earlier works assumed that if the initial size of LiFePO<sub>4</sub> particles is decreased and a small amount of a conducting additive is introduced (below 1%), anodic delithiation could be carried out to a greater extent.

In [529], it was found using a combination of the methods of Moessbauer spectroscopy and X-ray diffraction analysis that the boundary layer between the LiFePO<sub>4</sub> and FePO<sub>4</sub> crystal phases has an amorphous structure and the thickness of several nanometers. Later, the same authors confirmed these inferences using neutron diffraction analysis and concluded that it is the slow diffusion and low conductivity that determine irreversible capacity (i.e., nonextractable lithium) at not too low current densities [530, 531].

A more detailed analysis of the phase diagram of the FePO<sub>4</sub>–LiFePO<sub>4</sub> system showed that it is characterized by narrow regions of Li<sub>x</sub>FePO<sub>4</sub> solid solutions ( $\alpha < x < 1 - \beta$ ), where  $\alpha = 0.032$  and  $\beta = 0.038$  at the room temperature [532]. Thus, the main mass of the material consists not of the FePO<sub>4</sub> and LiFePO<sub>4</sub> phases, but of the Li <sub>$\alpha$</sub> FePO<sub>4</sub> and Li<sub>1 -  $\beta$</sub> FePO<sub>4</sub> phases. This conclusion was predicted in [533] and confirmed in [534].

In [511], olivine was obtained by direct solid-phase interaction of stoichiometric mixtures of the corresponding initial compounds (iron acetate, ammonium phosphate, and lithium carbonate) in an inert atmosphere under stepwise increase in the tem-

perature (300–350°C, and then 800°C). Later, this technology was used in [529, 535–540]. An effective improvement of this method was mechanical activation [520, 541–546]. An alternative solid–phase synthesis is hydrothermal synthesis used in [541, 542, 547–549] and the lately widely spread sol–gel method [513, 518, 522, 550–559]. A variety of the sol–gel method is the so called template synthesis [516, 560].

Recently, communications appeared on synthesis of composites of LiFePO<sub>4</sub> directly with nanostructured carbon forms (free graphene, carbon nanotubes etc) [561–564], and also application of thin–film electrodes [565, 566].

Correctly manufactured electrodes based on the LiFePO<sub>4</sub>/C composites are characterized by capacity close to the theoretical value even under appreciable loads. For example, data on capacity of 160 mA h/g [552] under discharge in the C/5 mode and above 120 mA h/g under discharge in the 5 C mode are presented.

Up till now, formidable literature is published on LiFePO<sub>4</sub>. A good review is found in [567].

### 3.2. Vanadium Oxide–Based Materials

Vanadium oxides have long been attracting researchers as a promising material for reversible insertion of lithium and therefore as a positive electrode material. A fundamental advantage of vanadium oxides before all conventional positive electrode materials, not excepting and LiFePO<sub>4</sub>, is that lithium insertion into conventional oxides is limited by a change in the valency of the oxide–forming metal by only 1 unit (Co<sup>3+</sup> → Co<sup>4+</sup>, Mn<sup>3+</sup> → Mn<sup>4+</sup>, Fe<sup>2+</sup> → Fe<sup>3+</sup>), while in the case of, e.g., reduction of vanadium pentoxide its valency can, in principle, change by 3 units (from +5 to +2). Thus, one could theoretically expect that vanadium oxides would possess a higher specific capacity. Unfortunately, lithium insertion into the crystal lattice of vanadium oxide is related to significant structural changes. An orthorhombic V<sub>2</sub>O<sub>5</sub> layered crystal structure ( $\alpha$ -V<sub>2</sub>O<sub>5</sub> phase) is characterized by a weak vanadium–oxygen bond, which facilitates reversible insertion of small cations, such as Li<sup>+</sup> (see, e.g., [568, 569]) according to the equation of



In the potential range of 3.5 to 2.5 V, reversible insertion of 1 mol of lithium per 1 mol of V<sub>2</sub>O<sub>5</sub> with formation of a  $\delta$ -V<sub>2</sub>O<sub>5</sub> phase occurs. In the further reduction (for example, up to the potential of 1.5 V), insertion of 3 atoms of lithium per 1 mol of V<sub>2</sub>O<sub>5</sub> is possible. Already insertion of 2 mols of lithium per 1 mol of V<sub>2</sub>O<sub>5</sub> results in formation of the  $\gamma$ -V<sub>2</sub>O<sub>5</sub> phase with an irreversible change in the structure (see, e.g., [570–573]). Many works have lately appeared where it has been shown that reversible insertion of lithium into vanadium pentoxide is possible either when electrodes in the form of very thin films or various nanostructures

are used. Thin-film electrodes based on vanadium oxides are primarily intended for microbatteries, including, completely solid-state ones. Rather many different methods of manufacturing thin-film electrodes of vanadium oxides are described, including radio-frequency magnetron deposition of  $V_2O_5$  [574–577], pulsed laser deposition [578, 579], vacuum deposition of amorphous  $V_2O_5$  [580–586], plasma-induced vacuum deposition [587], anodic [588–592] or thermal [569, 593–595] metal oxidation. Thin-film electrodes manufactured of  $V_2O_5$  xerogels using the spin-coating technique in [596] and thermal treatment of a  $V_2O_5$  gel in [597] were described. In some cases, rather high values of specific capacity were indeed obtained on thin-film electrodes. For example, capacity of more than 450 mA h/g for 100 cycles at the current of C/10 in [586] was obtained for films with the thickness of 200 nm. As a rule, an increase in the film thickness results in a decrease in specific capacity.

Literature on nanostructures of nonthin-film electrodes is much more fragmented. A rather complex procedure of manufacturing of  $V_2O_5$  nanofibers is described using the spin-coating technique in [598]. Electrodes with such a material had capacity of about 300 mA h/g. The method of manufacturing nanocrystalline nanorods with the diameters of 100–200 nm is described in [599], while the methods of  $V_2O_5$  nanotube manufacturing are given in [600–602] and the method of nanoband manufacturing is presented in [603]. Finally, paper [604] describes different unidimensional nanostructures with the capacity of 200–300 mA h/g. Very effective nanostructures are xerogels and aerogels [596, 605–614]. Data in the literature on the properties of xerogels and aerogels are very contradictory, but there are also indications regarding development of electrodes with very low specific capacity values. Thus, paper [605] describes electrodes capable of reversible insertion of 1.9 atoms of lithium per  $V_2O_5$  formula unit and paper [609] describes electrodes reversible inserting 2.9 lithium atoms; the latter value corresponds to specific capacity of 410 mA h/g.

One of the faults of  $V_2O_5$  xerogels is the relatively low electron conductivity. It was found that the doping of xerogels by small amounts of silver [615], copper [615–618], manganese [619] cations promotes an increase in conductivity and significant improvement of cyclability of such electrodes.

Lately, composite materials containing vanadium oxides (in the form of xerogels or nanotubes) and conducting polymers, such as polyaniline [620–626], polypyrrole [623, 627–631], polythiophene [627], polyethylene glycol [632], polyvinyl pyrrolidone [633], etc. gained wide acceptance. Introduction of conducting polymers also promotes an increase in conductivity of composites, their specific capacity and stability under cycling.

Finally, one should mention the composite of electrolytic  $V_2O_5$  with carbon also featuring enhanced spe-

cific capacity (280 mA h/g under discharge to 2 V) [634].

Of materials based on pentavalent vanadium oxide, of special interest is lithium trivanadate  $LiV_3O_8$  [635–645]. Lithium trivanadate has a layered structure consisting of bands of octahedral  $[VO_6]$  and trigonal  $[VO_5]$  fragments. These bands are bound between themselves through  $Li^+$  ions [646]. Such a structure provides the possibility of reversible intercalation of a relatively high amount of lithium, at least 4.5  $Li^+$  ion per  $LiV_3O_8$  formula unit [647], which corresponds to specific capacity of 419 mA h/g.  $LiV_3O_8$  is usually obtained by solid-state and sol-gel methods, and microwave heating is often used in the latter case [648, 649]. Electrochemical properties of lithium trivanadate largely depend on its crystalline structure; there is evidence of the fact that amorphous structures are preferable [650–656]. Similar to  $V_2O_5$ , lithium trivanadate is often used in the form of thin films [657] or in the form of nanostructured materials [658–663]. Attempts were made to dope trivanadate by other elements (silicon [664], fluorine [665], yttrium [666]), but these attempts proved to be of little success.

A material of great interest, with its role and importance as yet not fully determines, is vanadium–lithium phosphate  $Li_3V_2(PO_4)_3$  [667–684]. Such a material in monoclinic modification can reversibly extract and intercalate three lithium ions per formula unit, which corresponds to reversible capacity of 197 mA h/g. Actual capacities of up to 160 mA h/g are obtained. The working potential range of an electrode with such a material is 4.5–3.5 V under discharge and 3.5–4.8 V under charging, so that the safety of lithium-ion batteries with the vanadium–lithium phosphate remains problematic. The discharge and charging curves often contain clear steps corresponding to extraction (or intercalation) of the first, second, and third lithium ions at the potentials of about 4.0, 3.6, and 3.5 V. Electron conductivity of  $Li_3V_2(PO_4)_3$  is rather low: about  $2.3 \times 10^{-8}$  S/cm. Therefore, such a material is often used in the form of a composite with carbon (by analogy with  $LiFePO_4$ ). Similar to other materials, vanadium–lithium phosphate is also used in the form of thin-film electrodes [685]. There are reports of doping vanadium–lithium phosphate by iron [686] and chromium [687].

### 3.3. High-Voltage Materials

Of particular interest are the so called high-voltage materials, i.e., materials, with lithium insertion/extraction occurring at the potentials close to 5 V. The first class of such materials described by the formula of  $LiMn_{1/3}Ni_{1/3}Co_{1/3}O_4$  is sufficiently well studied [688], though studies of such materials are still continued [689]. Discharge capacity of such materials is about 170 mA h/g, which does not significantly exceed discharge capacity of conventional cathodic materials of lithium-ion batteries. However, an

increased discharge voltage implies an increase in specific energy of lithium-ion batteries at least by 30%.

Doped lithium-manganese spinels with the composition of  $\text{LiNi}_{0.5}\text{Mn}_{1.5}\text{O}_4$  also belong to high-voltage cathodic materials and are characterized by a single charging-discharge plateau in the potential range of 4.7 V [690, 691]. Additional doping of such spinels, e.g., by titanium or chromium, results in an increase in discharge voltage, acceleration of diffusion of solid-phase lithium ions, and also an increase in the charging-discharge current densities. Another dopant type for  $\text{LiNi}_{0.5}\text{Mn}_{1.5}\text{O}_4$  is the light element of F. When a part of oxygen atoms is replaced by fluorine, discharge capacitance generally decreases, but stability under cycling grows considerably [691].

Lithiated cobalt phosphate ( $\text{LiCoPO}_4$ ), same as  $\text{LiFePO}_4$ , has low electron conductivity, so that its use as the cathodic material is possible only in the case of synthesis of the  $\text{LiCoPO}_4/\text{C}$  composite [692, 693]. Such composites can be discharged at the potentials of 4.7–4.8 V. However, cyclability of such composites is very low, as decomposition of liquid electrolyte occurs under charging in the potential range of 4.8–5.1 V simultaneously with oxidation of  $\text{Co}^{2+}$  to  $\text{Co}^{3+}$ . The initial discharge capacity of  $\text{LiCoPO}_4/\text{C}$  is close to the theoretical one that is about 167 mA h/g.

A new class of high-voltage cathodic materials is fluorinated lithium phosphates. Lithiated vanadium fluorovanadate ( $\text{LiVPO}_4\text{F}$ ) is characterized by the discharge potential of 4.5 V. However, discharge capacity at a relative low discharge rate (1 C) does not exceed 130 mA h/g [694]. Of much greater interest are fluorinated cobalt phosphates. The theoretical capacity of such materials is twice higher as compared to that of lithiated iron and cobalt phosphates and the process of lithium insertion/extraction occurs at the potentials of 4.8–5.1 V. The combination of high discharge capacity and high voltage allows assuming that specific energy consumption of such materials would be at least 2.5–3 times higher than specific energy consumption of lithiated cobalt oxide. The authors of [695, 696] reported the results of studying  $\text{Li}_2\text{CoPO}_4\text{F}$  they synthesized as the cathodic material of lithium-ion batteries. It was confirmed that  $\text{Li}_2\text{CoPO}_4\text{F}$  is a new class of 5-V cathodic materials similar to  $\text{LiCoPO}_4$ . A fault of both  $\text{Li}_2\text{CoPO}_4\text{F}$  and lithiated cobalt phosphate is high irreversible capacity (especially in the first cycles), which is related to decomposition of electrolyte at high anodic potentials.

#### 4. CONCLUSION.

#### MAIN TRENDS IN DEVELOPMENT OF NEW-GENERATION BATTERIES

Operation of a lithium-ion battery is based on the ability of certain materials of reversibly intercalating (inserting) lithium ions. Negative electrodes of the up-to-date lithium-ion batteries are made of graphite, into which lithium is intercalated under battery

charging and the positive electrodes are made of lithiated oxides of transition metals, particularly, of the  $\text{LiCoO}_2$  compound, from which a part of lithium is extracted under charging. The specific capacity of graphite electrodes is 350–360 mA h/g, which is close to the theoretical limit (372 mA h/g), specific capacity of conventional positive electrodes is 120–140 mA h/g. The discharge voltage of lithium-ion batteries is 3.6–3.7 V; their charging voltage is above 4 V. With account for these values, specific energy of the modern lithium-ion batteries is about 200 W h/kg. The further increase in specific capacity of lithium-ion batteries is possible only when the electrode materials are replaced by fundamentally new materials. A vast number of studies in the recent 10–15 years is dedicated to the search for alternative materials for both the negative and positive electrodes, but up till now, the most of lithium-ion batteries are produced in the conventional version.

The necessity of replacing the electrode materials is also determined by the fact that the conventional electrochemical system (a carbon negative electrode and a positive electrode based on lithium cobaltite or lithium-manganese spinels) does not provide reliable safety in the course of battery operation. This problem has lately become especially severe and one of the ways for its solution consists in replacement of the positive electrode material by the material operating at less positive potentials. This certainly results in a decrease in the working voltage and preservation of specific energy requires that the electrode material would have increased specific capacity. Of the diversity of materials suggested recently for the negative electrode, the most attractive appear to be the materials based on amorphous silicon or silicon-carbon composites. Iron-lithium phosphate is generally accepted as the main alternative to the conventional positive electrode materials. At the same time, of great promise are nanostructured materials based on vanadium oxides. A new class of 5-V cathodic materials, e.g., such as  $\text{Li}_2\text{CoPO}_4\text{F}$  can be considered as an alternative to  $\text{LiCoO}_2$  if electrolytes are used that are stable at the potentials above 5 V.

#### REFERENCES

1. Nagaura, T. and Tozawa, K., *Progr. Batt. Solar Cells*, 1990, vol. 9, p. 209.
2. *Sony's New Lithium Ion Rechargeable Battery, Ed. Materials and Performance, JES Battery Newsletter*, Kozawa, A. and Fueki, K., Eds, no. 5, Sept.–Oct.
3. Nagaura, T. In: *5th Int. Seminar Lith. Batt. Techn. and Appl. March 4–6, 1991, Deerfield Beach, Fla*, p. 255.
4. Dahn, J.R., Fong, R., and Spoon, M.J., *Phys. Rev. B*, 1990, vol. 42, p. 6424.
5. Scrosati, B., *J. Electrochem. Soc.*, 1992, vol. 139, p. 2776.

6. *Lithium batteries: Science and Technology*, Nazri, G.-A. and Pistoia, G., Eds, Boston: Kluwer Academic Publishers, 2004.
7. Kedrinskii, I.A. and Yakovlev, V.G., *Li-ionnye akkumulyatory* (Li-Ion Batteries), Krasnoyarsk: IPK "Platina", 2002.
8. *Lithium Ion Batteries: Fundamentals and Performance*, Wakihara, O. and Yamamoto, O., Eds, Weinheim: Wiley-VCH, 1998.
9. *Lithium batteries. New Materials, Development and Perspectives*, Pistoia, G., Ed., New-York: Elsevier, 1994.
10. *Nonaqueous Electrochemistry*, Aurbach, D., Ed., New-York: Marcel Decker, Inc., 1999.
11. *Handbook of Battery Materials*, Besenhard, J.O., Ed., New York: Wiley-VCH Verlag GmbH, 1999.
12. Scrosati, B., *Nature*, 1995, vol. 373, p. 557.
13. Scrosati, B. and Garche, J., *J. Power Sources*, 2010, vol. 195, p. 2419.
14. Idota, Y., Kubota, T., Matsufuji, A., Maekawa, Y., and Miyasaka, T., *Science*, 1997, vol. 276, p. 1395.
15. Courtney, I.A. and Dahn, J.R., *J. Electrochem. Soc.*, 1997, vol. 144, p. 2045.
16. Courtney, I.A. and Dahn, J.R., *J. Electrochem. Soc.*, 1997, vol. 144, p. 2943.
17. Liu, W.F., Huang, X.J., Wang, Z.X., Li, H., and Chen, L.Q., *J. Electrochem. Soc.*, 1998, vol. 145, p. 59.
18. Brousse, T., Retoux, R., Herterlich, U., and Schleich, D., *J. Electrochem. Soc.*, 1998, vol. 145, p. 1.
19. Courtney, I.A., McKinnon, W.R., and Dahn, J.R., *J. Electrochem. Soc.*, 1999, vol. 146, p. 59.
20. Nam, S.C., Paik, C.H., Cho, W.I., Cho, B.W., Chun, H.S., and Yun, K.S., *J. Power Sources*, 1999, vol. 84, p. 24.
21. Ding, F., Fu, Z., Zhou, M., and Qin, Q., *J. Electrochem. Soc.*, 1999, vol. 146, p. 3554.
22. Li, N., Martin, C.R., and Scrosati, B., *Electrochem. Solid-State Lett.*, 2000, vol. 3, p. 316.
23. Lytle, Ju.C., Yan, H., Ergang, N.S., Smyrl, W.H., and Stein, A., *J. Mater. Chem.*, 2004, vol. 14, p. 1616.
24. Morales, J. and Sanchez, L., *J. Electrochem. Soc.*, 1999, vol. 146, p. 1640.
25. Wang, Y. and Lee, J.Y., *J. Phys. Chem. B*, vol. 108, p. 17832.
26. Uchiyama, H., Hosono, E., Honma, I., Zhou, H., and Imai, H., *Electrochim. Commun.*, 2008, vol. 10, p. 52.
27. Chou, S.-L., Wang, J.-Z., Liu, H.-K., and Dou, S.-X., *Electrochim. Commun.*, 2009, vol. 11, p. 242.
28. Wang, Y., Lee, J.Y., and Zeng, H.C., *Chem. Mater.*, 2005, vol. 17, p. 3899.
29. Zhang, Y., Liu, Y., and Liu, M., *Chem. Mater.*, 2006, vol. 18, p. 4643.
30. Ng, S.H., Santos, D.I., Chew, S.Y., Wexler, D., Wang, J., Dou, S.X., and Liu, H.K., *Electrochim. Commun.*, 2007, vol. 9, p. 915.
31. Ortiz, G.F., Alcantara, R., and Tirado, J.L., *Electrochim. Solid-State Lett.*, 2007, vol. 10, p. A286.
32. Song, J., Cai, M.-Z., Dong, Q.-F., Zheng, M.-S., Wu, Q.-H., and Wu, S.-T., *Electrochim. Acta*, 2009, vol. 54, p. 2748.
33. Nam, S.C., Yoon, Y.S., Cho, W.I., Cho, B.W., Chun, H.S., and Yun, K.S., *Electrochim. Commun.*, 2001, vol. 3, p. 6.
34. Nuli, Y.-N., Zhao, S.-L., and Qin, Q.-Z., *J. Power Sources*, 2003, vol. 114, p. 113.
35. Zhao, Y., Zhou, Q., Liu, L., Xu, J., Yan, M., and Jiang, Z., *Electrochim. Acta*, 2006, vol. 51, p. 2639.
36. Naichao, Li. and Charles, R., Martin, J., *Electrochim. Soc.*, 2001, vol. 148, p. A164.
37. Nam, S.C., Yoon, Y.S., Cho, W.I., Cho, B.W., Chun, H.S., and Yun, K.S., *J. Electrochim. Soc.*, 2001, vol. 148, p. A220.
38. Mohamedi, M., Lee, Seo-Jae, Takahashi, D., Nishizawa, M., Itoh, T., and Uchida, I., *Electrochim. Acta*, 2001, vol. 46, p. 1161.
39. Wang, Y. and Chen, T., *Electrochim. Acta*, 2009, vol. 54, p. 3510.
40. Yu, A. and Frech, R., *J. Power Sources*, 2002, vol. 104, p. 97.
41. Yu, Y., Gu, L., Dhanabalan, A., Chen, C.-H., and Wang, C., *Electrochim. Acta*, 2009, vol. 54, p. 7227.
42. Lou, X.W., Wang, Y., Yuan, C., Lee, J.Y., and Archer, L.A., *Adv. Mater.*, 2006, vol. 18, p. 2325.
43. Ahn, H.-J., Choi, H.-C., Park, K.-W., Kim, S.-B., and Sung, Y.-E., *J. Phys. Chem. B*, vol. 108, p. 9815.
44. Wang, Y., Lee, J.Y., and Zeng, H.C., *Chem. Mater.*, 2005, vol. 17, p. 3899.
45. Han, S., Jang, B., Kim, T., Oh, S.M., and Hyeon, T., *Adv. Funct. Mater.*, 2005, vol. 15, p. 1845.
46. Deng, D. and Lee, J.Y., *Chem. Mater.*, 2008, vol. 20, p. 1841.
47. Qiao, H., Zheng, Z., Zhang, L., and Xiao, L., *J. Mater. Sci.*, 2008, vol. 43, p. 2778.
48. Wen, Z., Wang, Q., Zhang, Q., and Li, J., *Adv. Funct. Mater.*, 2007, vol. 17, p. 2772.
49. Zhu, J., Lu, Z., Aruna, S.T., Aurbach, D., and Gedanken, A., *Chem. Mater.*, 2000, vol. 12, p. 2557.
50. Kim, C., Noh, M., Choi, M., Cho, J., and Park, B., *Chem. Mater.*, 2005, vol. 17, p. 3297.
51. Yang, S., Song, H., Yi, H., Liu, W., Zhang, H., and Chen, X., *Electrochim. Acta*, 2009, vol. 55, p. 521.
52. Xie, J. and Varadhan, V.K., *Mater. Chem. Phys.*, 2005, vol. 91, p. 274.
53. Liu, H., Long, D., Liu, X., Qiao, W., Zhan, L., and Ling, L., *Electrochim. Acta*, 2009, vol. 54, p. 5782.
54. Jhan, Y.R., Duh, J.G., Yang, M.H., and Shieh, D.T., *J. Power Sources*, 2009, vol. 193, p. 810.
55. Wang, Z., Chen, G., and Xia, D., *J. Power Sources*, 2008, vol. 184, p. 432.
56. Read, J., Foster, D., Wolfenstein, J., and Behl, W., *J. Power Sources*, 2001, vol. 96, p. 277.
57. Wang, Y. and Lee, J.Y., *J. Power Sources*, 2005, vol. 144, p. 220.
58. Lee, J.Y., Zhang, R., and Liu, Z., *J. Power Sources*, 2000, vol. 90, p. 70.
59. Lee, J.K., Ryu, D.H., Beck, J.J., Shul, Y.G., Cho, B.W., and Park, D., *J. Power Sources*, 2002, vol. 107, p. 90.
60. Xiao, T., Tang, Y., Jia, Z., and Feng, S., *Electrochim. Acta*, 2009, vol. 54, p. 2396.

61. Morimoto, H., Tatsumisago, M., and Minami, T., *Electrochim. Solid-State Lett.*, 2001, vol. 4, p. A16.
62. Huang, H., Kelder, E.M., Chen, L., and Schoonman, J., *J. Power Sources*, 1999, vol. 81–82, p. 362.
63. Liang, Y., Fan, J., Xia, X.-H., Luo, Y.-S., and Jia, Z.-J., *Electrochim. Acta*, 2007, vol. 52, p. 5891.
64. Wang, G., Gao, X.P., and Shen, P.W., *J. Power Sources*, 2009, vol. 192, p. 719.
65. Zhu, X.J., Geng, L.M., Zhang, F.Q., Liu, Y.X., and Cheng, L.B., *J. Power Sources*, 2009, vol. 189, p. 828.
66. Wang, Y. and Chen, T., *Electrochim. Acta*, 2009, vol. 54, p. 3510.
67. Poizot, P., Laurelle, S., Gruegeon, S., Dupont, L., and Tarascon, J.M., *Nature*, 2000, vol. 407, p. 496.
68. Tarascon, J.-M. and Armand, M., *Nature*, 2001, vol. 414, p. 359.
69. Gruegeon, S., Laruelle, S., Herrera-Urbina, R., Dupont, L., Poizot, P., and Tarascon, J.-M., *J. Electrochem. Soc.*, 2001, vol. 148, p. A285.
70. Poizot, P., Laurelle, S., Gruegeon, S., Dupont, L., and Tarascon, J.-M., *J. Power Sources*, 2001, vol. 97–98, p. 235.
71. Debart, A., Dupont, L., Poizot, P., Leriche, J.-B., and Tarascon, J.M., *J. Electrochem. Soc.*, 2001, vol. 148, p. A1266.
72. Wang, G.X., Chen, Y., Konstantinov, K., Lindsay, M., Liu, H.K., and Dou, S.X., *J. Power Sources*, 2002, vol. 109, p. 142.
73. Do, J.-S. and Weng, C.-H., *J. Power Sources*, 2006, vol. 159, p. 323.
74. Huang, X.H., Tu, J.P., Xia, X.H., Wang, X.L., Xiang, J.Y., Zhang, L., and Zhou, Y., *J. Power Sources*, 2009, vol. 188, p. 588.
75. Ke, F.-S., Huang, L., Wei, G.-Z., Xue, L.-J., Li, J.-T., Zhang, B., Chen, S.-R., Fan, X.-Y., and Sun, S.-G., *Electrochim. Acta*, 2009, vol. 54, p. 5825.
76. Xiang, J.Y., Tu, J.P., Huang, X.H., and Yang, Y.Z., *J. Solid State Electrochem.*, 2008, vol. 12, p. 941.
77. Pan, Q., Jin, H., Wang, H., and Yin, G., *Electrochim. Acta*, 2007, vol. 53, p. 951.
78. Gao, X.P., Bao, J.L., Pan, G.L., Zhu, H.Y., Huang, P.X., Wu, F., and Song, D.Y., *J. Phys. Chem. B*, 2008, vol. 108, p. 5547.
79. Park, J.C., Kim, J., Kwon, H., and Song, H., *Adv. Mater.*, 2009, vol. 21, p. 803.
80. Wang, Y., Zhang, Y.-F., Liu, H.-R., Yu, S.-J., and Qin, Q.-Z., *Electrochim. Acta*, 2003, vol. 48, p. 4253.
81. Wang Y. and Qin, Q.-Z., *J. Electrochem. Soc.*, 2002, vol. 149, p. A873.
82. Hosono, E., Fujihara, S., Honma, I., and Zhou, H., *Electrochim. Commun.*, 2006, vol. 8, p. 284.
83. Huang, X.H., Tu, J.P., Zhang, C.Q., and Xiang, J.Y., *Electrochim. Commun.*, 2007, vol. 9, p. 1180.
84. Lee, Y.H., Leu, I.C., Chang, S.T., Liao, C.L., and Fung, K.Z., *Electrochim. Acta*, 2004, vol. 50, p. 553.
85. Souza, E.A., Landers, R., Cardoso, L.P., Cruz-Tersio, G.S., Tabacniks, M.H., and Gorenstein, A., *J. Power Sources*, 2006, vol. 155, p. 358.
86. Morales, J., Sanchez, L., Martin, F., Ramos-Barardo, J.R., and Sanchez, M., *Electrochim. Acta*, 2004, vol. 49, p. 4589.
87. Needham, S.A., Wang, G.X., and Liu, H.K., *J. Power Sources*, 2006, vol. 159, p. 254.
88. Zhang, P., Guo, Z.P., Kang, S.G., Choi, Y.J., Kim, C.J., Kim, K.W., and Liu, H.K., *J. Power Sources*, 2009, vol. 189, p. 566.
89. Chen, L.B., Lu, N., Xu, C.M., Yu, H.C., and Wang, T.H., *Electrochim. Acta*, 2009, vol. 54, p. 4198.
90. Pan, Q., Wang, M., and Wang, Z., *Electrochim. Solid-State Lett.*, 2009, vol. 12, p. A50.
91. Xiang, J.Y., Tu, J.P., Yuan, Y.F., Wang, X.L., Huang, X.H., and Zeng, Z.Y., *Electrochim. Acta*, 2009, vol. 54, p. 1160.
92. Fu, L.J., Gao, J., Zhang, T., Cao, Q., Yang, L.C., Wu, Y.P., Holze, R., and Wu, H.Q., *J. Power Sources*, 2007, vol. 174, p. 1197.
93. Wang, H., Pan, Q., Cheng, Y., Zhao, J., and Yin, G., *Electrochim. Acta*, 2009, vol. 54, p. 2851.
94. Do, J.-S. and Dai, R.-F., *J. Power Sources*, 2009, vol. 189, p. 204.
95. Li, F., Zou, Q.-Q., and Xia, Y.-Y., *J. Power Sources*, 2008, vol. 177, p. 546.
96. Qiao, H., Xiao, L., Zheng, Z., Liu, H., Jia, F., and Zhang, L., *J. Power Sources*, 2008, vol. 185, p. 486.
97. Larcher, D., Sudant, G., Leriche, J.-B., Chabre, Y., and Tarascon, J.-M., *J. Electrochem. Soc.*, 2002, vol. 149, p. A234.
98. Yao, W., Yang, J., Wang, J., and Nuli, Y., *J. Electrochem. Soc.*, 2008, vol. 155, p. A903.
99. Liu, Y., Mi, C., Su, L., and Zhang, X., *Electrochim. Acta*, 2008, vol. 53, p. 2507.
100. Liu, H.-C. and Yen, S.-K., *J. Power Sources*, 2007, vol. 166, p. 478.
101. Oh, S.W., Bang, H.J., Bae, Y.C., and Sun, Y.K., *J. Power Sources*, 2007, vol. 173, p. 502.
102. Wang, G., Shen, X., Yao, J., Wexler, D., Ahn, J.-H., *Electrochim. Commun.*, 2009, vol. 11, p. 546.
103. Kang, Y.-M., Song, M.-S., Kim, J.-H., Kim, H.-S., Park, M.-S., Lee, J.-Y., Liu, H.K., and Dou, S.X., *Electrochim. Acta*, 2005, vol. 50, p. 3667.
104. Zhao, Z.W., Guo, Z.P., and Liu, H.K., *J. Power Sources*, 2005, vol. 147, p. 264.
105. Yang, R., Wang, Z., Liu, J., and Chen, L., *Electrochim. Solid-State Lett.*, 2004, vol. 7, p. A496.
106. Liu, H., Bo, S., Cui, W., Li, F., Wang, C., and Xia, Y., *Electrochim. Acta*, 2008, vol. 53, p. 6497.
107. Chou, S.-L., Wang, J.-Z., Liu, H.-K., and Dou, S.-X., *J. Power Sources*, 2008, vol. 182, p. 359.
108. Vidal-Abarca, C., Lavela, P., and Tirado, J.L., *Electrochim. Solid-State Lett.*, 2008, vol. 11, p. A198.
109. Wang, G., Shen, X., and Yao, J., *J. Power Sources*, 2009, vol. 189, p. 543.
110. Liu, Y. and Zhang, X., *Electrochim. Acta*, 2009, vol. 54, p. 4180.
111. Xia, X.H., Tu, J.P., Xiang, J.Y., Huang, X.H., Wang, X.L., and Zhao, X.B., *J. Power Sources*, 2010, vol. 195, p. 2014.

112. Lu, Y., Wang, Y., Zou, Y., Jiao, Z., Zhao, B., He, Y., and Wu, M., *Electrochim. Commun.*, 2010, vol. 12, p. 101.
113. Li, W.-Y., Xu, L.-N., and Chen, J., *Adv. Funct. Mater.*, 2005, vol. 15, p. 851.
114. Du, N., Zhang, H., Chen, B., Wu, J., Ma, X., Liu, Z., Zhang, Y., Yang, D., Huang, X., and Tu, J., *Adv. Mater.*, 2007, vol. 19, p. 4505.
115. Li, Y., Tan, B., and Wu, Y., *Nano Lett.*, 2008, vol. 8, p. 265.
116. Lou, X.W., Deng, D., Lee, J.Y., and Archer, L.A., *J. Mater. Chem.*, 2008, vol. 18, p. 4397.
117. Lou, X.W., Deng, D., Lee, J.Y., Feng, J., and Archer, L.A., *Adv. Mater.*, 2008, vol. 20, p. 258.
118. Zhang, H., Wu, J., Zhai, C., Ma, X., Du, N., Tu, J., and Yang, D., *Nanotechnology*, 2008, vol. 19, article no. 035711.
119. Wang, Y., Fu, Z.-W., and Qin, Q.-Z., *Thin Solid Films*, 2003, vol. 441, p. 19.
120. Fu, Z.-W., Wang, Y., Zhang, Y., and Qin, Q.-Z., *Solid State Ionics*, 2004, vol. 170, p. 105.
121. Wang, L., Xu, H.W., Chen, P.C., Zhang, D.W., Ding, C.X., and Chen, C.H., *J. Power Sources*, 2009, vol. 193, p. 846.
122. Liu, H., Wang, G., Park, J., Wang, J., Liu, H., and Zhang, C., *Electrochim. Acta*, 2009, vol. 54, p. 1733.
123. Larcher, D., Bonnin, D., Cortes, R., Rivals, I., Personnaz, L., and Tarascon, J.-M., *J. Electrochem. Soc.*, 2003, vol. 150, p. A1643.
124. Komaba, Sh., Mikumo, T., and Ogata, A., *Electrochim. Commun.*, 2008, vol. 10, p. 1276.
125. NuLi, Y., Zeng, R., Zhang, P., Guo, Z., and Liu, H., *J. Power Sources*, 2008, vol. 184, p. 456.
126. NuLi, Y., Zhang, P., Guo, Z., Munroe, P., Liu, H., *Electrochim. Acta*, 2008, vol. 53, p. 4213.
127. Hang, B.T., Okada, S., and Yamaki, J., *J. Power Sources*, 2008, vol. 178, p. 402.
128. Matsumura, T., Sonoyama, N., Kanno, R., and Takano, M., *Solid State Ionics*, 2003, vol. 158, p. 253.
129. Morimoto, H., Toboshima, S., and Iizuka, Y., *J. Power Sources*, 2005, vol. 146, p. 315.
130. Jain, G., Capozzi, C.J., and Xu, J.J., *J. Electrochem. Soc.*, 2003, vol. 150, p. A806.
131. Sharma, Y., Sharma, N., Subba Rao, G.V., and Chowdari, B.V.R., *J. Power Sources*, 2007, vol. 173, p. 495.
132. Alcántara, R., Jaraba, M., Lavela, P., Tirado, J.L., Jumas, J.C., and Olivier-Fourcade, J., *Electrochim. Commun.*, 2003, vol. 5, p. 16.
133. Lavela, P. and Tirado, J.L., *J. Power Sources*, 2007, vol. 172, p. 379.
134. Chu, Y.-Q., Fu, Z.-W., and Zong, Q., *Electrochimica Acta*, 2004, vol. 49, p. 4915.
135. Alcántara, R., Jaraba, M., Lavela, P., and Tirado, J.L., *Chem. Mater.*, 2002, vol. 14, p. 2847.
136. Ai, C., Yin, M., Wang, C., and Sun, J., *J. Mater. Sci.*, 2004, vol. 39, p. 1077.
137. Dupont, L., Grugeon, S., Laruelle, S., and Tarascon, J.-M., *J. Power Sources*, 2007, vol. 164, p. 839.
138. Dupont, L., Laruelle, S., Grugeon, S., Dickinson, C., Zhou, W., and Tarascon, J.-M., *J. Power Sources*, 2008, vol. 175, p. 502.
139. Fan, Q. and Whittingham, M.S., *Electrochim. Solid-State Lett.*, 2007, vol. 10, p. A48.
140. Yu, X.Q., He, Y., Sun, J.P., Tang, K., Li, H., Chen, L.Q., and Huang, X.J., *Electrochim. Commun.*, 2009, vol. 11, p. 791.
141. Ji, L. and Zhang, X., *Electrochim. Commun.*, 2009, vol. 11, p. 795.
142. Yang, L.C., Gao, Q.S., Zhang, Y.H., Tang, Y., and Wu, Y.P., *Electrochim. Commun.*, 2008, vol. 10, p. 118.
143. Jung, Y.S., Lee, S., Ahn, D., Dillon, A.C., and Lee, S.-H., *J. Power Sources*, 2009, vol. 188, p. 286.
144. Riley, L.A., Lee, Se-Hee., Gedvilias, L., and Dillon, A.C., *J. Power Sources*, 2010, vol. 195, p. 588.
145. Nam, K.T., Kim, D.-W., Yoo, P.J., Chiang, C.-Y., Meethong, N., Hammond, P.T., Chiang, Y.-M., and Belche, A.M., *Science*, 2006, vol. 312, p. 885.
146. Ki, T.N., Wartena, R., Yoo, P.J., Liau, F.W., Yun, J.L., Chiang, Y.-M., Hammond, P.T., and Belcher, A.M., *Proc. Natl. Acad. Sci. USA*, 2008, vol. 105, p. 17227.
147. Yun, J.L., Yi, H., Kim, W.-J., Kang, K., Yun, D.S., Strano, M.S., Ceder, G., and Belcher, A.M., *Science*, 2009, vol. 324, p. 1051.
148. Yang, Z., Choi, D., Kerisit, S., and Rosso, K.M., Wang, D., Zhang, J., Graff, G., and Liu, J., *J. Power Sources*, 2009, vol. 192, p. 588.
149. Jiang, C., Honma, I., Kudo, T., and Zhou, H., *Electrochim. Solid-State Lett.*, 2007, vol. 10, p. A127.
150. Baudrin, E., Cassaignon, S., Koelsch, M., Jolivet, J.-P., Dupont, L., and Tarascon, J.-M., *Electrochim. Commun.*, 2007, vol. 9, p. 337.
151. Qiao, H., Wang, Y., Xiao, L., and Zhang, L., *Electrochim. Commun.*, 2008, vol. 10, p. 1280.
152. Kubiak, P., Pfanzelt, M., Geserick, J., Hormann, U., Husing, N., Kaiser, U., and Wohlfahrt-Mehrens, M., *J. Power Sources*, 2009, vol. 194, p. 1099.
153. Exnar, I., Kavan, L., Huang, S.Y., and Gratzel, M., *J. Power Sources*, 1997, vol. 68, p. 720.
154. Hardwick, L.J., Holzapfel, M., Novak, P., Dupont, L., and Baudrin, E., *Electrochim. Acta*, 2007, vol. 52, p. 5357.
155. Xu, J., Jia, C., Cao, B., and Zhang, W.F., *Electrochim. Acta*, 2007, vol. 52, p. 8044.
156. Bao, S.-J., Bao, Q.-L., Li, C.-M., and Dong, Z.-L., *Electrochim. Commun.*, 2007, vol. 9, p. 1233.
157. Kubiak, P., Geserick, J., Husing, N., and Wohlfahrt-Mehrens, M., *J. Power Sources*, 2008, vol. 175, p. 510.
158. Wang, Z., Liu, S., Chen, G., and Xia, D., *Electrochim. Solid-State Lett.*, 2007, vol. 10, p. A77.
159. Chen, J.S. and Lou, X.W., *Electrochim. Commun.*, 2009, vol. 11, p. 2332.
160. Reddy, M.A., Kishore, M.S., Pralong, V., Varadaraju, U.V., and Raveau, B., *Electrochim. Solid-State Lett.*, 2007, vol. 10, p. A29.
161. Reddy, M.A., Pralong, V., Varadaraju, U.V., and Raveau, B., *Electrochim. Solid-State Lett.*, 2008, vol. 11, p. A132.

162. Inaba, M., Oba, Ya., Niina, F., Murota, Y., Ogino, Y., Tasaka, A., and Hirota, K., *J. Power Sources*, 2009, vol. 189, p. 580.
163. Liu, D., Zhang, Y., Xiao, P., Garcia, B.B., Zhang, Q., Zhou, X., Jeong, Y.-H., and Cao, G., *Electrochim. Acta*, 2009, vol. 54, p. 6816.
164. Ortiz, G.F., Hanzu, I., Knauth, P., Lavela, P., Tirado, J.L., and Djenizian, T., *Electrochim. Acta*, 2009, vol. 54, p. 4262.
165. Kim, H., Kim, M.G., Shin, T.J., Shin, H.-J., Cho, J., *Electrochim. Commun.*, 2008, vol. 10, p. 1669.
166. An, L.P., Gao, X.P., Li, G.R., Yan, T.Y., Zhu, H.Y., and Shen, P.W., *Electrochim. Acta*, 2008, vol. 53, p. 4573.
167. Xu, J., Wang, Y., Li, Z., and Zhang, W.F., *J. Power Sources*, 2008, vol. 175, p. 903.
168. He, B.-L., Dong, B., and Li, H.-L., *Electrochim. Commun.*, 2007, vol. 9, p. 425.
169. Zhao, Z.W., Guo, Z.P., Wexler, D., Ma, Z.F., Wu, X., and Liu, H.K., *Electrochim. Commun.*, 2007, vol. 9, p. 697.
170. Qiao, H., Wang, Y., Xiao, L., and Zhang, L., *Electrochim. Commun.*, 2008, vol. 10, p. 1280.
171. Song, B., Liu, S., Jian, J., Lei, M., Wang, X., Li, H., Yu, J., and Chen, X., *J. Power Sources*, 2008, vol. 180, p. 869.
172. Yin, J. and Zhang, W.F., *J. Power Sources*, 2009, vol. 191, p. 614.
173. Zhang, W.F., *Electrochim. Acta*, 2008, vol. 53, p. 7863.
174. Lafont, U., Simonin, L., Gaberscek, M., and Kelder, E.M., *J. Power Sources*, 2007, vol. 174, p. 1104.
175. Park, C.-M., Chang, W.-S., Jung, H., Kim, J.-H., and Sohn, H.-J., *Electrochim. Commun.*, 2009, vol. 11, p. 2165.
176. Zeng, Z.Y., Tu, J.P., Huang, X.H., Wang, X.L., Zhao, X.B., and Li, K.F., *Electrochim. Solid-State Lett.*, 2008, vol. 11, p. A105.
177. Lindsay, M.J., Blackford, M.G., Attard, D.J., Luca, V., Skyllas-Kazacos, M., and Griffith, C.S., *Electrochim. Acta*, 2007, vol. 52, p. 6401.
178. Lindsay, M.J., Skyllas-Kazacos, M., and Luca, V., *Electrochim. Acta*, 2009, vol. 54, p. 3501.
179. Murphy, D.W., Cava, R.J., Zahurak, S.M., and Santoro, A., *Solid State Ionics*, 1983, vol. 9-10, p. 413.
180. Colbow, K.M., Dahn, J.R., and Haering, R.R., *J. Power Sources*, 1989, vol. 26, p. 397.
181. Ohzuku, T., Ueda, A., and Yamamoto, N., *J. Electrochem. Soc.*, 1995, vol. 142, p. 1431.
182. Scharner, S., Wepner, W., and Schmid-Beurmann, P., *J. Electrochem. Soc.*, 1999, vol. 146, p. 857.
183. Nakahara, K., Nakajima, R., Matsushima, T., and Majima, H., *J. Power Sources*, 2003, vol. 117, p. 131.
184. Robertson, A.D., Trevino, L., Tukamoto, H., and Irvine, J.T.S., *J. Power Sources*, 1999, vol. 81–82, p. 352.
185. Zagnib, K., Armand, M., and Gauthier, M., *J. Electrochem. Soc.*, 1998, vol. 145, p. 3135.
186. Nakayama, M., Ishida, Y., Ikuta, H., and Wakihara, M., *Solid State Ionics*, 1999, vol. 117, p. 265.
187. Zhong, Z., *Electrochim. Solid-State Lett.*, 2007, vol. 10, p. A267.
188. Kubiak, P., Garcia, A., Womes, M., Aldon, L., Olivier-Fourcade, J., Lippens, P.-E., and Jumas, J.-C., *J. Power Sources*, 2003, vol. 119–121, p. 626.
189. Huang, S., Wen, Z., Zhu, X., and Lin, Z., *J. Power Sources*, 2007, vol. 165, p. 408.
190. Shenouda, A.Y. and Murali, K.R., *J. Power Sources*, 2008, vol. 176, p. 332.
191. Chen, C.H., Vaughney, J.T., Jansen, A.N., Dees, D.W., Kahaian, A.J., Goacher, T., and Thackeray, M.M., *J. Electrochem. Soc.*, 2001, vol. 148, p. A102.
192. Zhao, H., Li, Y., Zhu, Z., Lin, J., Tian, Z., and Wang, R., *Electrochim. Acta*, 2008, vol. 53, p. 7079.
193. Mukai, K., Ariyoshi, K., and Ohzuku, T., *J. Power Sources*, 2005, vol. 146, p. 213.
194. Huang, S., Wen, Z., Gu, Z., and Zhu, X., *Electrochim. Acta*, 2005, vol. 50, p. 4057.
195. Wang, D., Xu, H.-Y., Gu, M., and Chen, Ch.-H., *Electrochim. Commun.*, 2009, vol. 11, p. 50.
196. Wolfenstine, J. and Allen, J.L., *J. Power Sources*, 2008, vol. 180, p. 582.
197. Liu, D.T., Ouyang, C.Y., Shu, J., Jiang, J., Wang, Z.X., and Chen, L.Q., *Phys. Status Solidi*, vol. 243, p. 1835.
198. Bao, Z.P., Guo, *Electrochim. Acta*, 2009, vol. 54, p. 4772.
199. Kim, J., Kim, S.-W., Gwon, H., Yoon, W.-S., and Kang, K., *Electrochim. Acta*, 2009, vol. 54, p. 5914.
200. Yi, T.-F., Shu, J., Zhu, Y.-R., Zhu, X.-D., Yue, C.-B., Zhou, A.-N., and Zhu, R.-S., *Electrochim. Acta*, 2009, vol. 54, p. 7464.
201. Huang, J. and Jiang, Z., *Electrochim. Acta*, 2008, vol. 53, p. 7756.
202. Huang, S., Wen, Z., Zhang, J., Gu, Z., and Xum X., *Solid State Ionics*, 2006, vol. 177, p. 851.
203. Wen, Z., Yang, X., and Huang, S., *J. Power Sources*, 2007, vol. 174, p. 1041.
204. Snyder, M.Q., Trebukhova, S.A., Ravdel, B., Wheeler, M.C., DiCarlo, J., Tripp, C.P., and DeSisto, W.J., *J. Power Sources*, 2007, vol. 165, p. 379.
205. Wang, G.J., Gao, J., Fu, L.J., Zhao, N.H., Wu, Y.P., and Takamura, T., *J. Power Sources*, 2007, vol. 174, p. 1109.
206. Shu, J., *Electrochim. Acta*, 2009, vol. 54, p. 2869.
207. Kim, J. and Cho, J., *Electrochim. Solid-State Lett.*, 2007, vol. 10, p. A81.
208. Jiang, C., Zhou, Y., Honma, I., Kudo, T., and Zhou, H., *J. Power Sources*, 2007, vol. 166, p. 514.
209. Huang, J. and Jiang, Z., *Electrochim. Solid-State Lett.*, 2008, vol. 11, p. A116.
210. Tang, Y.F., Yang, L., Qiu, Z., and Huang, J.S., *Electrochim. Commun.*, 2008, vol. 10, p. 1513.
211. Kulova, T.L., Skundin, A.M., Roginskaya, Yu.E., and Chibirova, F.Kh., *Russ. J. Electrochem.*, 2004, vol. 40, p. 432.
212. Kulova, T.L., Roginskaya, Yu.E., and Skundin, A.M., *Russ. J. Electrochem.*, 2005, vol. 41, p. 69.
213. Vassiliev, S.Yu., Yusipovich, A.I., Roginskaya, Yu.E., Chibirova, F.Kh., Skundin, A.M., and Kulova, T.L., *J. Solid State Electrochem.*, 2005, vol. 9, p. 698.

214. Roginskaya, Yu.E., Chibirova, F.Kh., Kulova, T.L., and Skundin, A.M., *Russ. J. Electrochem.*, 2006, vol. 42, p. 355.
215. Roginskaya, Yu.E., Chibirova, F.Kh., Kulova, T.L., and Skundin, A.M., *Russ. J. Electrochem.*, 2006, vol. 42, p. 915.
216. Winter, M. and Besenhard, J.O., *Electrochim. Acta*, 1999, vol. 45, p. 31.
217. Valvo, M., Lafont, U., Munao, D., and Kelder, E.M., *J. Power Sources*, 2009, vol. 189, p. 297.
218. Zhang, T., Fu, L.J., Gao, J., Wu, Y.P., Holze, R., and Wu, H.Q., *J. Power Sources*, 2007, vol. 174, p. 770.
219. Hosono, E., Matsuda, H., Honma, I., Ichihara, M., and Zhou, H., *J. Electrochem. Soc.*, 2007, vol. 154, p. A146.
220. Sivashanmugam, A., Kumar, T.P., Renganathan, N.G., Gopukumar, S., Wohlfahrt-Mehrens, M., and Garche, J., *J. Power Sources*, 2005, vol. 144, p. 197.
221. Choi, W., Lee, J.Y., Jung, B.H., and Lim, H.S., *J. Power Sources*, 2004, vol. 136, p. 154.
222. Kim, J.-H., Khanal, S., Islam, M., Khatri, A., and Choi, D., *Electrochem. Commun.*, 2008, vol. 10, p. 1688.
223. Ui, K., Kikuchi, S., Kadoma, Y., Kumagai, N., and Ito, S., *J. Power Sources*, 2009, vol. 189, p. 224.
224. Hu, R.Z., Zhang, L., Liu, X., Zeng, M.Q., and Zhu, M., *Electrochem. Commun.*, 2008, vol. 10, p. 1109.
225. Hassoun, J., Panero, S., and Scrosati, B., *Electrochem. Commun.*, 2007, vol. 9, p. 1239.
226. Bazin, L., Mitra, S., Taberna, P.L., Poizot, P., Gressier, M., Menu, M.J., Barnabe, A., Simon, P., and Tarascon, J.-M., *J. Power Sources*, 2009, vol. 188, p. 578.
227. Li, Q., Hu, S., Wang, H., Wang, F., Zhong, X., and Wang, X., *Electrochim. Acta*, 2009, vol. 54, p. 5884.
228. Morimoto, H., Tobishima, S., and Negishi, H., *J. Power Sources*, 2005, vol. 146, p. 469.
229. Whitehead, A.H., Elliott, J.M., and Owen, J.R., *J. Power Sources*, 1999, vol. 81–82, p. 33.
230. Inaba, M., Uno, T., and Tasaka, A., *J. Power Sources*, 2005, vol. 146, p. 473.
231. Tamura, N., Ohshita, R., Fujimoto, M., Fujitani, S., Kamino, M., and Yonezu, I., *J. Power Sources*, 2002, vol. 107, p. 48.
232. Lee, S.-J., Lee, H.-Y., Jeong, S.-H., Baik, H.-K., and Lee, S.-M., *J. Power Sources*, 2002, vol. 111, p. 345.
233. Zhao, Z.W., Guo, Z.P., Wexler, D., Ma, Z.F., Wu, X., and Liu, H.K., *Electrochem. Commun.*, 2007, vol. 9, p. 697.
234. Fung, Y.S. and Zhu, D.R., *J. Electrochem. Soc.*, 2002, vol. 149, p. A319.
235. Kepler, K.D., Vaughey, J.T., and Thackeray, M.M., *J. Power Sources*, 1999, vol. 81–82, p. 383.
236. Xia, Y., Sakai, T., Fujieda, T., Wada, M., and Yoshinaga, H., *J. Electrochem. Soc.*, 2001, vol. 148, p. A471.
237. Yao, M., Okuno, K., Iwaki, T., Awazu, T., and Sakai, T., *J. Power Sources*, 2007, vol. 195, p. 2077.
238. Hu, R.Z., Zeng, M.Q., and Zhu, M., *Electrochim. Acta*, 2009, vol. 54, p. 2843.
239. Kim, D.J., Kim, H., Sohn, H.-J., and Kang, T., *J. Power Sources*, 2002, vol. 104, p. 221.
240. Wolfenstine, J., Campos, S., Foster, D., Read, J., and Behl, W.K., *J. Power Sources*, 2002, vol. 109, p. 230.
241. Ke, F.-Sh., Huang, L., Cai, J.-Sh., and Sun, Sh.-G., *Electrochim. Acta*, 2007, vol. 52, p. 6741.
242. Pu, W., He, X., Ren, J., Wan, C., and Jiang, C., *Electrochim. Acta*, 2005, vol. 50, p. 4140.
243. Larcher, D. and Beaulieu, L.Y., MacNeil D.D., Dahn J.R., *J. Electrochem. Soc.*, 2000, vol. 147, p. 1658.
244. Beattie, S.D. and Dahn, J.R., *J. Electrochem. Soc.*, 2003, vol. 150, p. A894.
245. Finke, A., Poizot, P., Guery, C., and Tarascon, J.-M., *J. Electrochem. Soc.*, 2005, vol. 152, p. A2364.
246. Tamura, N., Ohshita, R., Fujimoto, M., Kamino, M., and Fujitani, S., *J. Electrochem. Soc.*, 2003, vol. 150, p. A679.
247. Shin, H.-C. and Liu, M., *Adv. Funct. Mater.*, 2005, vol. 15, p. 582.
248. Fan, X.-Y., Ke, F.-S., Wei, G.-Z., Huang, L., and Sun, S.-G., *Electrochim. Solid-State Lett.*, 2008, vol. 11, p. A195.
249. Ju, S.H., Jamg, H.C., and Kang, Y.C., *J. Power Sources*, 2009, vol. 189, p. 163.
250. Wang, G.X., Sun, L., Bradhurst, D.H., Dou, S.X., and Liu, H.K., *J. Alloys Compd.*, 2000, vol. 299, p. L12.
251. Lee, H.-Y., Jang, S.-W., Lee, S.-M., Lee, S.-J., and Baik, H.-K., *J. Power Sources*, 2002, vol. 112, p. 8.
252. Cheng, X.-Q. and Shi, P.-F., *J. Alloys Compd.*, 2005, vol. 391, p. 241.
253. Mukaibo, H., Sumi, T., Yokoshima, T., Momma, T., and Osaka, T., *Electrochim. Solid-State Lett.*, 2, vol. 6, p. A218.
254. Amadei, I., Panero, S., Scrosati, B., Cocco, G., and Schiffini, L., *J. Power Sources*, 2005, vol. 143, p. 227.
255. Dong, Q.F., Wu, C.Z., Jin, M.G., Huang, Z.C., Zheng, M.S., You, J.K., and Lin, Z.G., *Solid State Ionics*, 2004, vol. 167, p. 49.
256. Hassoun, J., Panero, S., and Scrosati, B., *J. Power Sources*, 2006, vol. 160, p. 1336.
257. Huang, L., Wei, H.-B., Ke, F.-S., Fan, X.-Y., Li, J.-T., and Sun, S.-G., *Electrochim. Acta*, 2009, vol. 54, p. 2693.
258. Hassoun, J., Panero, S., Simon, P., Taberna, P.L., and Scrosati, B., *Adv. Mater.*, 2007, vol. 19, p. 1632.
259. Guo, H., Zhao, S., Zhao, H., and Chen, Y., *Electrochim. Acta*, 2009, vol. 54, p. 4040.
260. Qin, H., Zhao, X., Jiang, N., and Li, Z., *J. Power Sources*, 2007, vol. 171, p. 948.
261. Kim, Y.-L., Lee, H.-Y., Jang, S.-W., Lee, S.-J., Baik, H.-K., Yoon, Y.-S., Park, Y.-S., and Lee, S.-M., *Solid State Ionics*, 2003, vol. 160, p. 235.
262. Ehrlich, G.M., Durand, C., Chen, X., Hugener, T.A., Spiess, F., and Suib, S.L., *J. Electrochem. Soc.*, 2000, vol. 147, p. 886.
263. Crosnier, O., Brousse, T., Devaux, X., Fragnaud, P., and Schleich, D.M., *J. Power Sources*, 2001, vol. 94, p. 169.

264. Ahn, J.-H., Wang, G.X., Yao, J., Liu, H.K., and Dou, S.X., *J. Power Sources*, 2003, vol. 119–121, p. 45.
265. Mukaibo, H., Momma, T., and Osaka, T., *J. Power Sources*, 2005, vol. 146, p. 457.
266. Nishikawa, K., Fukunaka, Y., Sakka, T., Ogata, Y., and Selman, J.R., *J. Power Sources*, 2007, vol. 174, p. 668.
267. Naille, S., Ionica-Bousquet, C.M., Robert, F., Morato, F., Lippens, P.-E., and Olivier-Fourcade, J., *J. Power Sources*, 2007, vol. 174, p. 1091.
268. Nishikawa, K., Dokko, K., and Kinoshita, K., Woo Sang-Wook, Kanamura K., *J. Power Sources*, 2009, vol. 189, p. 726.
269. Naille, S., Dedryvere, R., Zitoun, D., and Lippens, P.-E., *J. Power Sources*, 2009, vol. 189, p. 806.
270. Tamura, N., Fujimoto, M., Kamino, M., and Fujitani, S., *Electrochim. Acta*, 2004, vol. 49, p. 1949.
271. Zhang, J.-J. and Xia, Y.-Y., *J. Electrochem. Soc.*, 2006, vol. 153, p. A1466.
272. Ke, F.S., Huang, L., Wei, H.-B., Cai, J.-S., Fan, X.-Y., Yang, F.-Z., and Sun, S.-G., *J. Power Sources*, 2007, vol. 170, p. 450.
273. Guo, H., Zhao, H., Jia, X., Li, X., and Qiu, W., *Electrochim. Acta*, 2007, vol. 52, p. 4853.
274. Valvo, M., Lafont, U., Simonin, L., and Kelder, E.M., *J. Power Sources*, 2007, vol. 174, p. 428.
275. Fan, Q., Chupas, P.J., and Whittingham, M.S., *Electrochim. Solid-State Lett.*, 2007, vol. 10, p. A274.
276. Alcantara, R., Ortiz, G., Rodriguez, I., and Tirado, J.L., *J. Power Sources*, 2009, vol. 189, p. 309.
277. Xie, J., Zhao, X.B., Cao, G.S., and Tu, J.P., *J. Power Sources*, 2007, vol. 164, p. 386.
278. Wachtler, M., Besenhard, J.O., and Winter, M., *J. Power Sources*, 2001, vol. 94, p. 189.
279. Zhao, H., Yin, C., Guo, H., and Qiu, W., *Electrochim. Solid-State Lett.*, 2006, vol. 9, p. A281.
280. Fernandez-Madrigal, F.J., Lavela, P., Vicente, C.P., Tirado, J.L., Jumas, J.C., Olivier-Fourcade, J., *Chem. Mater.*, 2002, vol. 14, p. 2962.
281. Yang, J., Takeda, Y., Imanishi, N., Ichikawa, T., and Yamamoto, O., *Solid State Ionics*, 2000, vol. 135, p. 175.
282. Trifonova, A., Wachtler, M., Wagner, M.R., Schroettner, H., Mitterbauer, Ch., Hofer, F., Moller, K.-C., Winter, M., and Besenhard, J.O., *Solid State Ionics*, 2004, vol. 168, p. 51.
283. Wachtler, M., Winter, M., and Besenhard, J.O., *J. Power Sources*, 2002, vol. 105, p. 151.
284. Li, H., Zhu, G., Huang, X., and Chen, L., *J. Mater. Chem.*, 2000, vol. 10, p. 693.
285. Besenhard, J.O., Wachtler, M., Winter, M., Andreaus, R., Rom, I., and Sitte, W., *J. Power Sources*, 1999, vol. 81–82, p. 268.
286. Yang, J., Takeda, Y., Imanishi, N., and Yamamoto, O., *J. Electrochem. Soc.*, 1999, vol. 146, p. 4009.
287. Simonin, L., Lafont, U., and Kelder, E.M., *J. Power Sources*, 2008, vol. 180, p. 859.
288. Zhao, H., Jiang, C., He, X., and Ren, J., *J. Power Sources*, 2008, vol. 184, p. 532.
289. Li, H., Shi, L., Lu, W., Huang, X., and Chen, L., *J. Electrochem. Soc.*, 2001, vol. 148, p. A915.
290. Zhao, H., Yin, C., Guo, H., He, J., Qiu, W., and Li, Y., *J. Power Sources*, 2007, vol. 174, p. 916.
291. Winter, M., Besenhard, J.O., Spahr, M.E., and Novak, P., *Adv. Mater.*, 1998, vol. 10, p. 725.
292. Mao, O., and Dahn, J.R., *J. Electrochem. Soc.*, 1999, vol. 146, p. 414.
293. Wang, L., Kitamura, S., Sonoda, T., Obata, K., Tanase, S., and Sakai, T., *J. Electrochem. Soc.*, 2003, vol. 150, p. A1346.
294. Fang, L. and Chowdari, B.V.R., *J. Power Sources*, 2001, vol. 97–98, p. 181.
295. Sakaguchi, H., Maeta, H., Kubota, M., Honda, H., and Esaka, T., *Electrochemistry*, 2000, vol. 68, p. 632.
296. Sakaguchi, H., Honda, H., Akasaka, Y., and Esaka, T., *J. Power Sources*, 2003, vol. 119–121, p. 50.
297. Yin, J., Wada, M., Tanase, S., and Sakai, T., *J. Electrochem. Soc.*, 2004, vol. 151, p. A867.
298. Ronnebro, E., Yin, J., Kitano, A., Wada, M., Tanase, Sh., and Sakai, T., *J. Electrochem. Soc.*, 2005, vol. 152, p. A152.
299. Zhang, J.-J., Zhang, X., and Xia, Y.-Y., *J. Electrochem. Soc.*, 2007, vol. 154, p. A7.
300. Vaughey, J.T., Owejan, J., and Thackeray, M.M., *Electrochim. Solid-State Lett.*, 2007, vol. 10, p. A220.
301. Guo, H., Zhao, H., Jia, X., He, J., Qiu, W., and Li, X., *J. Power Sources*, 2007, vol. 174, p. 921.
302. Matsuno, S., Kohno, T., Takami, N., Kawashima, F., and Sawa, T., *Electrochim. Solid-State Lett.*, 2005, vol. 8, p. A234.
303. Beattie, S.D. and Dahn, J.R., *J. Electrochem. Soc.*, 2005, vol. 152, p. C542.
304. Yin, J., Wada, M., Tanase, S., and Sakai, T., *J. Electrochem. Soc.*, 2004, vol. 151, p. A583.
305. Wang, F., Zhao, M., and Song, X., *J. Power Sources*, 2008, vol. 175, p. 558.
306. Tabuchi, T., Hochgatterer, N., Ogumi, Z., and Winter, M., *J. Power Sources*, 2009, vol. 188, p. 552.
307. Kim, I.-S., Blomgren, G.E., and Kumta, P.N., *Electrochim. Solid-State Lett.*, 2004, vol. 7, p. A44.
308. Grigoriants, I., Soffer, A., Salitra, G., and Aurbach, D., *J. Power Sources*, 2005, vol. 146, p. 185.
309. Morishita, T., Hirabayashi, T., Okuni, T., Ota, N., and Inagaki, M., *J. Power Sources*, 2006, vol. 160, p. 638.
310. Veeraraghavan, B., Durairajan, A., Haran, B., Popov, B., and Guidotti, R., *J. Electrochim. Soc.*, 2002, vol. 149, p. A675.
311. Egashira, M., Takatsuji, H., Okada, S., and Yamaki, J.-I., *J. Power Sources*, 2002, vol. 107, p. 56.
312. Wang, G.X., Yao, J., Liu, H.K., Dou, S.X., and Ahn, J.-H., *Electrochim. Acta*, 2004, vol. 50, p. 517.
313. Balan, L., Schneider, R., Ghanbaja, J., Willmann, P., and Billaud, D., *Electrochim. Acta*, 2006, vol. 51, p. 3385.
314. Guo, B., Shu, J., Tang, K., Bai, Y., Wang, Z., and Chen, L., *J. Power Sources*, 2008, vol. 177, p. 205.
315. Zou, L., Gan, L., Kang, F., Wang, M., Shen, W., and Huang, Z., *J. Power Sources*, 2010, vol. 195, p. 1216.

316. Lee, J.H., Kong, B.-S., Yang, S.B., and Jung, H.-T., *J. Power Sources*, 2009, vol. 194, p. 520.
317. Park, J.W., Eom, J.-Y., and Kwon, H.S., *Electrochem. Commun.*, 2009, vol. 11, p. 596.
318. Zhao, L.Z., Hu, S.J., Ru, Q., Li, W.S., Hou, X.H., Zeng, R.H., and Lu, D.S., *J. Power Sources*, 2008, vol. 184, p. 481.
319. Trifonova, A., Winter, M., and Besenhard, J.O., *J. Power Sources*, 2007, vol. 174, p. 800.
320. Marcinek, M., Hardwick, L.J., Richardson, T.J., Song, X., and Kostecki, R., *J. Power Sources*, 2007, vol. 173, p. 965.
321. Zhao, H., Jiang, C., He, X., Ren, J., and Wan, C., *Electrochim. Acta*, 2007, vol. 52, p. 7820.
322. Wang, Y., Lee, J.Y., and Chen, B.-H., *J. Electrochem. Soc.*, 2004, vol. 151, p. A563.
323. Huang, L., Cai, J.-S., He, Y., Ke, F.-S., and Sun, S.-G., *Electrochem. Commun.*, 2009, vol. 11, p. 950.
324. Guo, Z.P., Zhao, Z.W., Liu, H.K., and Dou, S.X., *Carbon*, 2005, vol. 43, p. 1392.
325. Ferguson, P.P., Martine, M.L., George, A.E., and Dahn, J.R., *J. Power Sources*, 2009, vol. 194, p. 794.
326. Hassoun, J., Panero, S., Mulas, G., and Scrosati, B., *J. Power Sources*, 2007, vol. 171, p. 928.
327. Ferguson, P.P. and Dahn, J.R., *Electrochim. Solid-State Lett.*, 2008, vol. 11, p. A187.
328. Chen, Z., Qian, J., Ai, X., Cao, Y., and Yang, H., *J. Power Sources*, 2009, vol. 189, p. 730.
329. Lee, S.-I., Yoon, S., Park, C.-M., Lee, J.-M., Kim, H., Im, D., Doo, S.-G., and Sohn, H.-J., *Electrochim. Acta*, 2008, vol. 54, p. 364.
330. Guo, H., Zhao, H., and Jia, X., *Electrochim. Commun.*, 2007, vol. 9, p. 2207.
331. Dahn, J.R., Mar, R.E., and Abouzeid, A., *J. Electrochem. Soc.*, 2006, vol. 153, p. A361.
332. Todd, A.D.W., Mar, R.E., and Dahn, J.R., *J. Electrochem. Soc.*, 2007, vol. 154, p. A597.
333. Mao, O., Dunlap, R.A., and Dahn, J.R., *J. Electrochem. Soc.*, 1999, vol. 146, p. 405.
334. Beaulieu, L.Y. and Dahn, J.R., *J. Electrochem. Soc.*, 2000, vol. 147, p. 3237.
335. Lewis, R.B., Timmons, A., Mar, R.E., and Dahn, J.R., *J. Electrochem. Soc.*, 2007, vol. 154, p. A213.
336. Ferguson, P.P., Todd, A.D.W., and Dahn, J.R., *Electrochim. Commun.*, 2008, vol. 10, p. 25.
337. Hassoun, J., Mulas, G., Panero, S., and Scrosati, B., *Electrochim. Commun.*, 2007, vol. 9, p. 2075.
338. Park, C.-M. and Sohn, H.-J., *Electrochim. Acta*, 2009, vol. 54, p. 6367.
339. Hassoun, J., Derrien, G., Panero, S., and Scrosati, B., *Electrochim. Acta*, 2009, vol. 54, p. 4441.
340. Chang, C.-C., *J. Power Sources*, 2008, vol. 175, p. 874.
341. Sharma, R.A. and Seefurth, R.N., *J. Electrochem. Soc.*, 1976, vol. 123, p. 1763.
342. van der Marel, C., Vinke, G.J.B., and van der Lugt, W., *Solid State Commun.*, 1985, vol. 54, p. 917.
343. Wen, C.J. and Huggins, R.A., *J. Solid State Chem.*, 1981, V. 37, p. 271.
344. Weydanz, W.J., Wohlfahrt-Mehrens, M., and Huggins, R.A., *J. Power Sources*, 1999, vol. 81–82, p. 237.
345. Limthongkul, P., Jang, Y.-I., Dudney, N.J., and Chiang, Y.-M., *J. Power Sources*, 2003, vol. 119–121, p. 604.
346. Huggins, R.A., *Solid State Ionics*, 1998, vol. 113–115, p. 57.
347. Li, H., Huang, X., Chen, L., Wu, Z., and Liang, Y., *Electrochim. Solid State Lett.*, 1999, vol. 2, p. 547.
348. Bourderau, S., Brousse, T., and Schleich, D.M., *J. Power Sources*, 1999, vol. 81–82, p. 233.
349. Lee, S.-J., Lee, J.-K., Chung, S.-H., Lee, H.-Y., Lee, S.-M., and Baik, H.-K., *J. Power Sources*, 2001, vol. 97–98, p. 191.
350. Jung, H., Park, M., Yoon, Y.-G., Kim, G.-B., and Joo, S.-K., *J. Power Sources*, 2003, vol. 115, p. 346.
351. Netz, A., Huggins, R.A., and Weppner, W., *J. Power Sources*, 2003, vol. 119–121, p. 95.
352. Ohara, S., Suzuki, J., Sekine, K., and Takamura, T., *J. Power Sources*, 2003, vol. 119–121, p. 591.
353. Takamura, T., Ohara, S., Uehara, M., Suzuki, J., and Sekine, K., *J. Power Sources*, 2004, vol. 129, p. 96.
354. Lee, K.-L., Jung, J.-Y., Lee, S.-W., Moon, H.-S., and Park, J.-W., *J. Power Sources*, 2004, vol. 129, p. 270.
355. Lee, K.-L., Jung, J.-Y., Lee, S.-W., Moon, H.-S., and Park, J.-W., *J. Power Sources*, 2004, vol. 130, p. 241.
356. Ohara, S., Suzuki, J., Sekine, K., and Takamura, T., *J. Power Sources*, 2004, vol. 136, p. 303.
357. Zhang, Y., Fu, Z.-W., and Qin, Q.-Z., *Electrochim. Commun.*, 2004, vol. 6, p. 484.
358. Uehara, M., Suzuli, J., Tamura, K., Sekine, K., and Takamura, T., *J. Power Sources*, 2005, vol. 146, p. 441.
359. Yoshimura, K., Suzuki, J., Sekine, K., and Takamura, T., *J. Power Sources*, 2005, vol. 146, p. 445.
360. Moon, T., Kim, C., and Park, B., *J. Power Sources*, 2006, vol. 155, p. 391.
361. Maranchi, J.P., Hepp, A.F., Kumta, P.N., *Electrochim. Solid-State Lett.*, 2003, vol. 6, p. A198.
362. Hatchard, T.D. and Dahn, J.R., *J. Electrochem. Soc.*, 2004, vol. 151, p. A838.
363. Beaulieu, L.Y., Eberman, K.W., Krause, L.J., and Dahn, J.R., *Electrochim. Solid-State Lett.*, 2001, vol. 4, p. A137.
364. Beaulieu, L.Y., Hewitt, K.C., Turner, R.L., Bonakdarpour, A., Abdo, A.A., Eberman, K.W., Krause, L.J., and Dahn, J.R., *J. Electrochem. Soc.*, 2003, vol. 150, p. A149.
365. Beaulieu, L.Y., Hatchard, T.D., Bonakdarpour, A., Fleischauer, M.D., and Dahn, J.R., *J. Electrochem. Soc.*, 2003, vol. 150, p. A1457.
366. Cho, G.B., Song, M.G., Bae, S.H., Kim, J.K., Choi, Y.J., Ahn, H.J., Ahn, J.H., Cho, K.K., and Kim, K.W., *J. Power Sources*, 2009, vol. 189, p. 738–742.
367. Zhang, T., Zhang, H.P., Yang, L.C., Wang, B., Wu, Y.P., and Takamura, T., *Electrochim. Acta*, 2008, vol. 53, p. 5660.
368. Yin, J., Wada, M., Yamamoto, K., Kitano, Y., Tanase, S., and Sakai, T., *J. Electrochem. Soc.*, 2006, vol. 153, p. A472.

369. Maranchi, J.P., Hepp, A.F., Evans, A.G., Nuhfer, N.T., and Kumta, P.N., *J. Electrochem. Soc.*, 2006, vol. 153, p. A1246.
370. Takamura, T., Uehara, M., Suzuki, J., Sekine, K., and Tamura, K., *J. Power Sources*, 2006, vol. 158, p. 1401.
371. Maranchi, J.P., Hepp, A.F., and Kumta, P.N., *Electrochim. Solid-State Lett.*, 2003, vol. 6, p. A198.
372. Obrovac, M.N. and Christensen, L., *Electrochim. Solid-State Lett.*, 2004, vol. 7, p. A93.
373. Roginskaya, Yu.E., Kulova, T.L., Skundin, A.M., Bruk, M.A., Zhikharev, E.N., and Kal'nov, V.A., *Russ. J. Electrochem.*, 2008, vol. 44, p. 992.
374. Kulova, T.L. and Skundin, A.M., *Elektrokhim. Energ.*, 2010, vol. 10, p. 57.
375. Baranchugov, V., Markevich, E., Pollak, E., Salitra, G., and Aurbach, D., *Electrochim. Commun.*, 2007, vol. 9, p. 796.
376. Kulova, T.L., Skundin, A.M., Pleskov, Yu.V., Kon'kov, O.I., Terukov, E.I., and Trapeznikova, I.N., *Semiconductors*, 2006, vol. 40, p. 468.
377. Kulova, T.L., Skundin, A.M., Pleskov, Yu.V., Terukov, E.I., and Kon'kov, O.I., *Russ. J. Electrochem.*, 2006, vol. 42, p. 363.
378. Kulova, T.L., Skundin, A.M., Pleskov, Yu.V., Terukov, E.I., and Kon'kov, O.I., *Russ. J. Electrochem.*, 2006, vol. 42, p. 708.
379. Kulova, T.L., Skundin, A.M., Pleskov, Yu.V., Terukov, E.I., and Kon'kov, O.I., *J. Electroanal. Chem.*, 2007, vol. 600, p. 217.
380. Kulova, T.L., Skundin, A.M., Pleskov, Yu.V., Kon'kov, O.I., Terukov, E.I., and Trapeznikova, I.N., *Chem. Biochem. Eng. Q.*, 2007, vol. 21, p. 83.
381. Kulova, T.L. and Skundin, A.M., *Russ. J. Electrochem.*, 2010, vol. 46, p. 470.
382. Graetz, J., Ahn, C.C., Yazami, R., and Fultz, B., *Electrochim. Solid-State Lett.*, 2003, vol. 6, p. A194.
383. Park, M.S., Wang, G.X., Liu, H.K., and Dou, S.X., *Electrochim. Acta*, 2006, vol. 51, p. 5246.
384. Choi, N.-S., Yew, K.H., Kim, H., Kim, S.-S., and Choi, W.-U., *J. Power Sources*, 2007, vol. 172, p. 404.
385. Obrovac, M.N. and Krause, L.J., *J. Electrochem. Soc.*, 2007, vol. 154, p. A103.
386. Wang, C., Kakwan, I., Appleby, A.J., and Little, F.E., *J. Electroanal. Chem.*, 2000, vol. 489, p. 55.
387. Yoshio, M., Kugino, S., and Dimov, N., *J. Power Sources*, 2006, vol. 153, p. 375.
388. Xu, Y.H., Yin, G.P., Ma, Y.L., Zuo, P.J., and Cheng, X.Q., *J. Power Sources*, 2010, vol. 195, p. 2069.
389. Kasavajjula, U.S. and Wang, C., *Indian J. Chem., Sect A* 44, 2005, p. 975.
390. Liu, W.-R., Yang, M.-H., Wu, H.-C., Chiao, S.M., and Wu, N.-L., *Electrochim. Solid-State Lett.*, 2005, vol. 8, p. A100.
391. Li, J., Lewis, R.B., and Dahn, J.R., *Electrochim. Solid-State Lett.*, 2007, vol. 10, p. A17.
392. Ding, N., Xu, J., Yao, Y., Wegner, G., Lieberwirth, I., and Chen, C., *J. Power Sources*, 2009, vol. 192, p. 644.
393. Lestriez, B., Bahri, S., Sandu, I., Roué, L., and Guyomard, D., *Electrochim. Commun.*, 2007, vol. 9, p. 2801.
394. Choi, N.-S., Yew, K.H., Choi, W.-U., and Kim, S.-S., *J. Power Sources*, 2008, vol. 177, p. 590.
395. Chan, C.K., Peng, H., Liu, G., McIlwrath, K., Zhang, X.F., Huggins, R.A., and Cui, Y., *Nat. Nanotechnol.*, 2008, vol. 3, p. 31.
396. Chan, C.K., Ruffo, R., Hong, S., Huggins, R.A., and Cui, Y., *J. Power Sources*, 2009, vol. 189, p. 34.
397. Chan, C.K., Ruffo, R., Hong, S.S., and Cui, Y., *J. Power Sources*, 2009, vol. 189, p. 1132.
398. Ruffo, R., Hong, S.S., Chan, C.K., Huggins, R.A., and Cui, Y., *J. Phys. Chem. C*, 2009, vol. 113, p. 11390.
399. Cui, L.-F., Ruffo, R., Chan, C.K., Peng, H., and Cui, Y., *Nano Lett.*, 2009, vol. 9, p. 491.
400. Kasavajjula, U., Wang, C., and Appleby, A.J., *J. Power Sources*, 2007, vol. 163, p. 1003.
401. Wang, C.S., Wu, G.T., Zhang, X.B., Qi, Z.F., and Li, W.Z., *J. Electrochem. Soc.*, 1998, vol. 145, p. 2751.
402. Li, H., Huang, X., Chen, L., Wu, Z., and Liang, Y., *Electrochim. Solid-State Lett.*, 1999, vol. 2, p. 547.
403. Wang, G.X., Yao, J., and Liu, H.K., *Electrochim. Solid-State Lett.*, 2004, vol. 7, p. A250.
404. Niu, J. and Lee, J.Y., *Electrochim. Solid-State Lett.*, 2002, vol. 5, p. A107.
405. Dimov, N., Kugino, S., and Yoshio, M., *J. Power Sources*, 2004, vol. 136, p. 108.
406. Yoshio, M., Tsumura, T., and Dimov, N., *J. Power Sources*, 2005, vol. 146, p. 10.
407. Yoshio, M., Tsumura, T., and Dimov, N., *J. Power Sources*, 2006, vol. 163, p. 215.
408. Wang, G.X., Yao, J., and Liu, H.K., *Electrochim. Solid-State Lett.*, 2004, vol. 7, p. A250.
409. Kim, B.-C., Uono, H., Sato, T., Fuse, T., Ishihara, T., and Senna, M., *Solid State Ionics*, 2004, vol. 172, p. 33.
410. Dimov, N., Xia, Y., and Yoshio, M., *J. Power Sources*, 2007, vol. 171, p. 886.
411. Zhang, Y., Zhang, X.G., Zhang, H.L., Zhao, Z.G., Li, F., Liu, C., and Cheng, H.M., *Electrochim. Acta*, 2006, vol. 51, p. 4994.
412. Shu, J., Li, H., Yang, R., Shi, Y., and Huang, X., *Electrochim. Commun.*, 2006, vol. 8, p. 51.
413. Kim, T., Mo, Y.H., Nahm, K.S., and Oh, S.-M., *J. Power Sources*, 2006, vol. 162, p. 1275.
414. Eom, J.Y., Park, J.W., Kwon, H.S., and Rajendran, S., *J. Electrochem. Soc.*, 2006, vol. 153, p. A1678.
415. Wang, W. and Kumta, P.N., *J. Power Sources*, 2007, vol. 172, p. 650.
416. Wu, G.T., Wang, C.S., Zhang, X.B., Yang, H.S., Qi, Z.F., He, P.M., and Li, W.Z., *J. Electrochem. Soc.*, 1999, vol. 146, p. 1696.
417. Ishihara, T., Kawahara, A., Nishiguchi, H., Yoshio, M., and Takita, Y., *J. Power Sources*, 2003, vol. 119–121, p. 24.
418. Gao, B., Kleinhammes, A., Tang, X.P., Bower, C., Fleming, L., Wu, Y., and Zhou, O., *Chem. Phys. Lett.*, 1999, vol. 307, p. 153.
419. Maurin, G., Bousquet, Ch., Henn, F., Bernier, P., Almairac, R., and Simon, B., *Chem. Phys. Lett.*, 1999, vol. 312, p. 14.

420. Gao, B., Bower, C., Lorentzen, J.D., Fleming, L., Kleinhammes, A., Tang, X.P., McNeil, L.E., Wu, Y., and Zhou, O., *Chem. Phys. Lett.*, 2000, vol. 327, p. 69.
421. Frackowiak, E., Gautier, S., Gaucher, H., Bonnamy, S., and Beguin, F., *Carbon*, 1999, vol. 37, p. 61.
422. Claye, A.S., Fischer, J.E., Huffman, C.B., Rinzler, A.G., and Smalley, R.E., *J. Electrochem. Soc.*, 2000, vol. 147, p. 2845.
423. Shimoda, H., Gao, B., Tang, X.P., Kleinhammes, A., Fleming, L., Wu, Y., and Zhou, O., *Phys. B (Amsterdam, Neth.)*, 2002, vol. 323, p. 133.
424. Maurin, G., Henn, F., Simon, B., Colomer, J.-F., and Nagy, J.B., *Nano Lett.*, 2001, vol. 1, p. 75.
425. Leroux, F., Méténier, K., Gautier, S., Frackowiak, E., Bonnamy, S., and Béguin, F., *J. Power Sources*, 1999, vol. 81–82, p. 317.
426. Morris, R.S., Dixon, B.G., Gennett, T., Raffaelle, R., and Heben, M.J., *J. Power Sources*, 2004, vol. 138, p. 277.
427. Shin, H.-C., Liu, M., Sadanandan, B., and Rao, A.M., *J. Power Sources*, 2002, vol. 112, p. 216.
428. Wang, G.X., Ahn, J.-H., Yao, J., Lindsay, M., Liu, H.K., and Dou, S.X., *J. Power Sources*, 2003, vol. 119–121, p. 16.
429. Odani, A., Nimberger, A., Markovsky, B., Sominski, E., Levi, E., Kumar, V.G., Motie, M., Gedanken, A., Dan, P., and Aurbach, D., *J. Power Sources*, 2003, vol. 119–121, p. 517.
430. Eom, J.-Y., Kim, D.-Y., Kwon, H.S., *J. Power Sources*, 2006, vol. 157, p. 507.
431. Kumar, T.P., Stephan A.M., Thayananth, P., Subramanian, V., Gopukumar, S., Renganathan, N.G., Raghavan, M., and Muniyandi, N., *J. Power Sources*, 2001, vol. 97–98, p. 118.
432. Sharon, M., Hsu, W.K., Kroto, H.W., Walton, D.R.M., Kawahara, A., Ishihara, T., and Takita, Y., *J. Power Sources*, 2004, vol. 104, p. 148.
433. Ng, S.H., Wang, J., Guo, Z.P., Chen, J., Wang, G.X., and Liu, H.K., *Electrochim. Acta*, 2005, vol. 51, p. 23.
434. Yang, S., Song, H., Chen, X., Okotrub, A.V., and Bulusheva, L.G., *Electrochim. Acta*, 2007, vol. 52, p. 5286.
435. Mukhopadhyay, I., Hoshino, N., Kawasaki, S., Okino, F., Hsu, W.K., and Touhara, H., *J. Electrochem. Soc.*, 2002, vol. 149, p. A39.
436. Yang, Z., Wu, H.-Q., and Simard, B., *Electrochim. Commun.*, 2002, vol. 4, p. 574.
437. Frackowiak, E. and Béguin, F., *Carbon*, 2002, vol. 40, p. 1775.
438. Yang, Z.-H., Wu, H.-Q., *Solid State Ionics*, 2001, vol. 143, p. 173.
439. Zhang, X.-W., Patil, P.K., Wang, C., Appleby, A.J., Little, F.E., and Cocke, D.L., *J. Power Sources*, 2004, vol. 125, p. 206.
440. Kim, I.-S. and Kumta, P.N., *J. Power Sources*, 2004, vol. 136, p. 145.
441. Hanai, K., Liu, Y., Imanishi, N., Hirano, A., Matsumura, M., Ichikawa, T., and Takeda, Y., *J. Power Sources*, 2005, vol. 146, p. 156.
442. Yang, J., Wang, B.F., Wang, K., Liu, Y., Xie, J.Y., and Wen, Z.S., *Electrochem. Solid-State Lett.*, 2003, vol. 6, p. A154.
443. Kim, I.-S., Blomgren, G.E., and Kumta, P.N., *Electrochem. Solid-State Lett.*, 2004, vol. 7, p. A44.
444. Liu, Y., Hanai, K., Yang, J., Imanishi, N., Hirano, A., and Takeda, Y., *Electrochem. Solid-State Lett.*, 2004, vol. 7, p. A369.
445. Datta, M.K. and Kumta, P.N., *J. Power Sources*, 2007, vol. 165, p. 368.
446. Khomenko, V.G., Barsukov, V.Z., Doninger, J.E., and Barsukov, I.V., *J. Power Sources*, 2007, vol. 165, p. 598.
447. Wilson, A.M., Zank, G., Eguchi, K., Xing, W., and Dahn, J.R., *J. Power Sources*, 1997, vol. 68, p. 195.
448. Xing, W., Wilson, A.M., Zank, G., and Dahn, J.R., *Solid State Ionics*, 1997, vol. 93, p. 239.
449. Larcher, D., Mudalige, C., George, A.E., Porter, V., Gharghouri, M., and Dahn, J.R., *Solid State Ionics*, 1999, vol. 122, p. 71.
450. Wen, Z.S., Yang, J., Wang, B.F., Wang, K., and Liu, Y., *Electrochim. Commun.*, 2003, vol. 5, p. 165.
451. Ning, L.J., Wu, Y.P., Wang, L.Z., Fang, S.B., and Holze, R., *J. Solid State Electrochem.*, 2005, vol. 9, p. 520.
452. Xue, J.S., Myrtle, K., and Dahn, J.R., *J. Electrochem. Soc.*, 1995, vol. 142, p. 2927.
453. Xing, W., Wilson, A.M., Eguchi, K., Zank, G., and Dahn, J.R., *J. Electrochem. Soc.*, 1997, vol. 144, p. 2410.
454. Hayes, S.E., Eckert, H., Even, W.R., and Guidotti, R., *J. Electrochem. Soc.*, 1999, vol. 146, p. 2435.
455. Wilson, A.M., Reimers, J.N., Fuller, E.W., and Dahn, J.R., *Solid State Ionics*, 1994, vol. 74, p. 249.
456. Zuo, P., Yin, G., and Ma, Y., *Electrochim. Acta*, 2007, vol. 52, p. 4878.
457. Khomenko V.G. and Barsukov, V.Z., *Electrochim. Acta*, 2007, vol. 52, p. 2829.
458. Ng, S.H., Wang, J., Konstantinov, K., Wexler, D., Chew, S.Y., Guo, Z.P., and Liu, H.K., *J. Power Sources*, 2007, vol. 174, p. 823.
459. Guo, Z.P., Milin, E., Wang, J.Z., Chen, J., and Liu, H.K., *J. Electrochem. Soc.*, 2005, vol. 152, p. A2211.
460. Lee, J.-H., Kim, W.-J., Kim, J.-Y., Lim, S.-H., and Lee, S.-M., *J. Power Sources*, 2008, vol. 176, p. 353.
461. Luo, Z., Fan, D., Liu, X., Mao, H., Yao, C., and Deng, Z., *J. Power Sources*, 2009, vol. 189, p. 16.
462. Si, Q., Hanai, K., Imanishi, N., Kubo, M., Hirano, A., Takeda, Y., and Yamamoto, O., *J. Power Sources*, 2009, vol. 189, p. 761.
463. Uon, H., Kim, B.C., Fuse, T., Ue, M., and Yamaki, J., *J. Electrochem. Soc.*, 2006, vol. 153, p. A1708.
464. Datta, M.K. and Kumta, P.N., *J. Power Sources*, 2006, vol. 158, p. 557.
465. Zavyalov, S.A., Kulova, T.L., Kupriyanov, L.Yu., Roginskaya, Yu.E., and Skundin, A.M., *Russ. J. Phys. Chem. A*, 2008, vol. 82, no. 13, p. 2165.
466. Dimov, N., Fukuda, K., Umeno, T., Kugino, S., and Yosshio, M., *J. Power Sources*, 2003, vol. 114, p. 88.

467. Yoshio, M., Wang, H., Fukuda, K., Umeno, T., Dimov, N., and Ogumi, Z., *J. Electrochem. Soc.*, 2002, vol. 149, p. A1598.
468. Yang, X.-Q., McBreen, J., Yoon, W.-S., Yoshio, M., Wang, H., Fukuda, K., and Umeno, T., *Electrochim. Commun.*, 2002, vol. 4, p. 893.
469. Wilson, A.M. and Dahn, J.R., *J. Electrochem. Soc.*, 1995, vol. 142, p. 326.
470. Holzapfel, M., Buqa, H., Krumeich, F., Novák, P., Petrat, F.-M., and Veit, C., *Electrochim. Solid-State Lett.*, 2005, vol. 8, p. A516.
471. Liu, W.-R., Wang, J.-H., Wu, H.-Ch., Shieh, D.-T., Yang, M.-H., and Wu, N.-L., *J. Electrochim. Soc.*, 2005, vol. 152, p. A1719.
472. Alias, M., Crozier, O., Sandu, I., Jestin, G., Papadimopoulos, A., Le Cras, F., Schleich, D.M., and Brousse, T., *J. Power Sources*, 2007, vol. 174, p. 900.
473. Wang, G.X., Ahn, J.H., Yao, J., Bewlay, S., and Liu, H.K., *Electrochim. Commun.*, 2004, vol. 6, p. 689.
474. Buqa, H., Goers, D., Holzapfel, M., Spahr, M.E., and Novák, P., *J. Electrochim. Soc.*, 2005, vol. 152, p. A474.
475. Holzapfel, M., Buqa, H., Hardwick, L.J., Hahn, M., Würsig, A., Scheifele, W., Novák, P., Kötz, R., Veit, C., and Petrat, F.-M., *Electrochim. Acta*, 2006, vol. 52, p. 973.
476. Xie, J., Cao, G.S., and Zhao, X.B., *Mater. Chem. Phys.*, 2004, vol. 88, p. 295.
477. Wilson, A.M., Way, B.M., Dahn, J.R., and van Buuren, T., *J. Appl. Phys.*, 1995, vol. 77, p. 2363.
478. Chan, C.K., Patel, R.N., O'Connell, M.J., Korgel, B.A., and Cui, Y., *ACS Nano*, 2010, vol. 4, p. 1443.
479. Roginskaya, Yu.E., Kulova, T.L., Skundin, A.M., Bruk, M.A., Klochikhina, A.V., Kozlova, N.V., Kal'nov, V.A., and Loginov, B.A., *Russ. J. Phys. Chem. A*, 2008, vol. 82, p. 1655.
480. Bruk, M.A., Bespalov, V.A., Loginov, B.A., Loginov, V.B., Degtyarev, N.A., Degtyarev, N.A., Zefirov, I.D., Kal'nov, V.A., Klochikhina, A.V., Kulova, T.L., Roginskaya, Yu.E., and Skundin, A.M., *Inorg. Mater.*, 2008, vol. 44, p. 1086.
481. Roginskaya, Yu.E., Kulova, T.L., Skundin, A.M., Bruk, M.A., Zhikharev, E.N., Kal'nov, V.A., and Loginov, V.B., *Russ. J. Electrochim.*, 2008, vol. 44, p. 1197.
482. Yang, X., Wen, Z., Xu, X., Gu, Z., and Huang, Sh., *Electrochim. Solid-State Lett.*, 2007, vol. 10, p. A52.
483. Hwang, S.-M., Lee, H.-Y., Jang, S.-W., Lee, S.-M., Lee, S.-J., Baik, H.-K., and Lee, J.-Y., *Electrochim. Solid-State Lett.*, 2001, vol. 4, p. A97.
484. Wu, X., Wang, Z., Chen, L., and Huang, X., *Electrochim. Commun.*, 2003, vol. 5, p. 935.
485. Yang, X., Wen, Z., Huang, S., Zhu, X., and Zhang, X., *Solid State Ionics*, 2006, vol. 177, p. 2807.
486. Hatchard, T.D. and Dahn, J.R., *J. Electrochim. Soc.*, 2005, vol. 152, p. A1445.
487. Lee, H.-T., Kim, Y.-L., Hong, M.-K., and Lee, S.-M., *J. Power Sources*, 2005, vol. 141, p. 159.
488. Kim, H., Im, D., and Doo, S.G., *J. Power Sources*, 2007, vol. 174, p. 588.
489. Wang, G.X., Sun, L., Bradhurst, D.H., Zhong, S., Dou, S.X., and Liu, H.K., *J. Power Sources*, 2000, vol. 88, p. 278.
490. Park, M.-S., Lee, Y.-J., Rajendran, S., Song, M.-S., Kim, H.-S., and Lee, J.-Y., *Electrochim. Acta*, 2005, vol. 50, p. 5561.
491. Kim, T., Park, S., Oh, S.M., *Electrochim. Commun.*, 2006, vol. 8, p. 1461.
492. Lee, H.-Y. and Lee, S.-M., *J. Power Sources*, 2002, vol. 112, p. 649.
493. Dong, H., Feng, R.X., Ai, X.P., Cao, Y.L., and Yang, H.X., *Electrochim. Acta*, 2004, vol. 49, p. 5217.
494. Kim, J.-B., Lim, S.-H., and Lee, S.-M., *J. Electrochim. Soc.*, 2006, vol. 153, p. A455.
495. Ahn, H.-J., Kim, Y.-S., Kim, W.B., Sung, Y.E., and Seong, T.-Y., *J. Power Sources*, 2006, vol. 163, p. 211.
496. Kim, J.-H., Kim, H., and Sohn, H.-J., *Electrochim. Commun.*, 2005, vol. 7, p. 557.
497. Kim, B.-Ch., Uono, H., Satou, T., Fuse, T., Ishihara, T., Ue, M., and Senna, M., *J. Electrochim. Soc.*, 2005, vol. 152, p. A523.
498. Guo, Z.P., Zhao, Z.W., Liu, H.K., and Dou, S.X., *J. Power Sources*, 2005, vol. 146, p. 190.
499. Guo, Z.P., Wang, J.Z., Liu, H.K., and Dou, S.X., *J. Power Sources*, 2005, vol. 146, p. 448.
500. Liu, Y., Hanai, K., Matsumura, T., Imanishi, N., Hirano, A., and Takeda, Y., *Electrochim. Solid-State Lett.*, 2004, vol. 7, p. A492.
501. Rocka, N.L. and Kumta, P.N., *J. Power Sources*, 2007, vol. 164, p. 829.
502. Fleischauer, M.D., Topple, J.M., and Dahn, J.R., *Electrochim. Solid-State Lett.*, 2005, vol. 8, p. A137.
503. Liu, Y., Matsumura, T., Imanishi, N., Hirano, A., Ichikawa, T., and Takeda, Y., *Electrochim. Solid-State Lett.*, 2005, vol. 8, p. A599.
504. Lee, Y.-S., Lee, J.-H., Kim, Y.-W., Sun, Y.-K., Lee, S.-M., *Electrochim. Acta*, 2006, vol. 52, p. 1523.
505. Zuo, P., Yin, G., Zhao, J., Ma, Y., Cheng, X., Shi, P., and Takamura, T., *Electrochim. Acta*, 2006, vol. 52, p. 1527.
506. Yoon, S., Park, C.-M., Kim, H., and Sohn, H.-J., *J. Power Sources*, 2007, vol. 167, p. 520.
507. Chew, S.Y., Guo, Z.P., Wang, J.Z., Chen, J., Munroe, P., Ng, S.H., Zhao, L., and Liu, H.K., *Electrochim. Commun.*, 2007, vol. 9, p. 941.
508. Zhang, X.N., Huang, P.X., Li, G.R., Yan, T.Y., Pan, G.L., and Gao, X.P., *Electrochim. Commun.*, 2007, vol. 9, p. 713.
509. Yan, J.M., Huang, H.Z., Zhang, J., and Yang, Y., *J. Power Sources*, 2008, vol. 175, p. 547.
510. Padhi, A.K., Nanjundaswamy, K.S., and Goode-nough, J.B., *J. Electrochim. Soc.*, 1997, vol. 144, p. 1188.
511. Ravet, N., Chouinard, Y., Magnan, J.F., Besner, S., Gauthier, M., and Armand, M., *J. Power Sources*, 2001, vol. 97–98, p. 503.
512. Delacourt, C., Laffont, L., Bouchet, R., Wurm, C., Leriche, J.-B., Morcrette, M., Tarascon, J.-M., and Masquelier, C., *J. Electrochim. Soc.*, 2005, vol. 152, p. A913.

513. Delacourt, C., Poizot, P., Levasseur, S., and Masquelier, C., *Electrochem. Solid-State Lett.*, 2006, vol. 9, p. A352.
514. Gaberscek, M., Dominko, R., and Jamnik, J., *Electrochem. Commun.*, 2007, vol. 9, p. 2778.
515. Chen, Zh. and Dahn, J. R., *J. Electrochem. Soc.*, 2002, vol. 149, p. A1184.
516. Sides, C.R., Croce, F., Young, V.Y., Martin, C.R., and Scrosati, B., *Electrochem. Solid-State Lett.*, 2005, vol. 8, p. A484.
517. Shin, H.C., Cho, W.I., and Jang, H., *Electrochim. Acta*, 2006, vol. 52, p. 1472.
518. Kim, D.-H. and Kim, J., *Electrochem. Solid-State Lett.*, 2006, vol. 9, p. A439.
519. Song, M.-S., Kang, Y.-M., Kim, J.-H., Kim, H.-S., Kim, D.-Y., Kwon, H.-S., and Lee, J.-Y., *J. Power Sources*, 2007, vol. 166, p. 260.
520. Kwon, S.J., Kima, C.W., Jeong, W.T., and Lee, K.S., *J. Power Sources*, 2004, vol. 137, p. 93.
521. Kim, C.W., Park, J.S., and Lee, R.S., *J. Power Sources*, 2006, vol. 163, p. 144.
522. Dominko, R., Bele, M., Gaberscek, M., Remskar, M., Hanelz, D., Goupil, J.M., Pejovnik, S., and Jamnik, J., *J. Power Sources*, 2006, vol. 153, p. 274.
523. Gaberscek, M., Dominko, R., Bele, M., Remskar, M., and Jamnik, J., *Solid State Ionics*, 2006, vol. 177, p. 3015.
524. Liu, H., Cao, Q., Fu, L.J., Li, C., Wu, Y.P., and Wu, H.Q., *Electrochem. Commun.*, 2006, vol. 8, p. 1553.
525. Wang, G.X., Bewlay, S., Needham, S.A., Liu, H.K., Liu, R.S., Drozd, V.A., Lee, J.-F., and Chen, J.M., *J. Electrochem. Soc.*, 2006, vol. 153, p. A25.
526. Abbate, M., Lala, S.M., Montoro, L.A., and Rosolen, J.M., *Electrochem. Solid-State Lett.*, 2005, vol. 8, p. A288.
527. Padhi, A.K., Nanjundaswamy, K.S., Masquelier, C., Okada, S., and Goodenough, J.B., *J. Electrochem. Soc.*, 1997, vol. 144, p. 1609.
528. Okada, S., Sawa, S., Egashira, M., Yamaki, J.-I., Tabuchi, M., Kageyama, H., Konishi, T., and Yoshino, A., *J. Power Sources*, 2001, vol. 97–98, p. 430.
529. Andersson, A.S., Kalska, B., Häggström, L., and Thomas, J.O., *Solid State Ionics*, 2000, vol. 130, p. 41.
530. Andersson, A.S., Thomas, J.O., Kalska, B., and Häggström, L., *Electrochem. Solid-State Lett.*, 2000, vol. 3, p. 66.
531. Andersson, A.S. and Thomas, J.O., *J. Power Sources*, 2001, vol. 97–98, p. 498.
532. Yamada, A., Koizumi, H., Sonoyama, N., and Kanno, R., *Electrochem. Solid-State Lett.*, 2005, vol. 8, p. A409.
533. Srinivasan, V. and Newman, J., *J. Electrochem. Soc.*, 2004, vol. 151, p. A1517.
534. Dodd, J.L., Yazami, R., and Fultz, B., *Electrochem. Solid-State Lett.*, 2006, vol. 9, p. A151.
535. Takahashi, M., Tobishima, S., Takei, K., and Sakurai, Y., *J. Power Sources*, 2001, vol. 97–98, p. 508.
536. Yamada, A., Chung, S.C., and Hinokuma, K., *J. Electrochem. Soc.*, 2001, vol. 148, p. A224–A229.
537. Higuchi, M., Katayama, K., Azuma, Y., Yukava, M., and Suhara, M., *J. Power Sources*, 2003, vol. 119–121, p. 258.
538. Kim, H.-S., Cho, B.-W., and Cho, W.-I., *J. Power Sources*, 2004, vol. 132, p. 235.
539. Zhang, S.S., Allen, J.L., Xu, K., and Jow, T.R., *J. Power Sources*, 2005, vol. 147, p. 234.
540. Liu, H., Li, C., Zhang, H.P., Fu, L.J., Wu, Y.P., and Wu, H.Q., *J. Power Sources*, 2006, vol. 159, p. 717.
541. Franger, S., le Cras, F., Bourbon, C., and Rouault, H., *Electrochem. Solid-State Lett.*, 2002, vol. 5, p. A231.
542. Franger, S., Cras, F., Bourbon, C., and Rouault, H., *J. Power Sources*, 2003, vol. 119–121, p. 252.
543. Liao, X.-Z., Ma, Z.-F., Wang, L., Zhang, X.-M., Jiang, Y., and Hea, Y.S., *Electrochem. Solid-State Lett.*, 2004, vol. 7, p. A522.
544. Kim, C.W., Lee, M.H., Jeong, W.T., and Lee, K.S., *J. Power Sources*, 2005, vol. 146, p. 534.
545. Shin, H.C., Cho, W.I., and Jang, H., *J. Power Sources*, 2006, vol. 159, p. 1383.
546. Yun, N.J., Ha, H.W., Jeong, K.H., Park, H.Y., and Kim, K., *J. Power Sources*, 2006, vol. 160, p. 1361.
547. Yang, S., Zavalji, P.Y., and Whittingham, M.S., *Electrochem. Commun.*, 2001, vol. 3, p. 505.
548. Takeuchi, T., Tabuchi, M., Nakashima, A., Nakamura, T., Miwa, Y., Kageyama, H., and Tatsumi, K., *J. Power Sources*, 2005, vol. 146, p. 575.
549. Meligrana, G., Gerbaldi, C., Tuel, A., Bodoardo, S., and Penazzi, N., *J. Power Sources*, 2006, vol. 160, p. 516.
550. Croce, F., Epifanio, A.D., Hassoun, J., Deptula, A., Olczac, T., and Scrosati, B., *Electrochem. Solid-State Lett.*, 2002, vol. 5, p. A47.
551. Prosini, P.P., Carewska, M., Scaccia, S., Wisniewski, P., Passerini, S., and Pasquali, M., *J. Electrochem. Soc.*, 2002, vol. 149, p. A886.
552. Huang, H., Yin, S.-C., and Nazar, L.F., *Electrochem. Solid-State Lett.*, 2001, vol. 4, p. A170.
553. Yang, J. and Xu, J.J., *Electrochem. Solid-State Lett.*, 2004, vol. 7, p. A515.
554. Singhal, A., Skandan, G., Amatucci, G., Badway, F., Ye, N., Manthiram, A., Ye, H., and Xu, J.J., *J. Power Sources*, 2004, vol. 129, p. 38.
555. Ma, J. Qin, Q.-Z., *J. Power Sources*, 2005, vol. 148, p. 66.
556. Hsu, K.-F., Tsay, S.-Y., and Hwang, B.-J., *J. Power Sources*, 2005, vol. 146, p. 529.
557. Yang, M.-R., Ke, W.-H., and Wu, S.-H., *J. Power Sources*, 2005, vol. 146, p. 539.
558. Wang, G.X., Needham, S., Yao, J., Wang, J.Z., Liu, R.S., and Liu, H.K., *J. Power Sources*, 2006, vol. 159, p. 282.
559. Yang, J. and Xu, J.J., *J. Electrochem. Soc.*, 2006, vol. 153, p. A716.
560. Shi, Z., Li, Y., Ye, W., and Yang, Y., *Electrochem. Solid-State Lett.*, 2005, vol. 8, p. A396.
561. Ding, Y., Jiang, Y., Xu, F., Yin, J., Ren, H., Zhuo, Q., Long, Z., and Zhang, P., *Electrochem. Commun.*, 2010, vol. 12, p. 10.

562. Chen, J.-M., Hsu, C.-H., Lin, Y.-R., Hsiao, M.-H., Fey, G.T.-K., *J. Power Sources*, 2008, vol. 184, p. 498.
563. Bhuvaneswari, M.S., Bramnik, N.N., Ensling, D., Ehrenberg, H., and Jaegermann, W., *J. Power Sources*, 2008, vol. 180, p. 553.
564. Li, X., Kang, F., Bai, X., and Shen, W., *Electrochim. Commun.*, 2007, vol. 9, p. 663.
565. Tang, K., Sun, J., Yu, X., Li, H., and Huang, X., *Electrochim. Acta*, 2009, vol. 54, p. 6565.
566. Xie, J., Imanishi, N., Zhang, T., Hirano, A., Takeda, Y., and Yamamoto, O., *Electrochim. Acta*, 2009, vol. 54, p. 4631.
567. Jugović, D. and Uskoković, D., *J. Power Sources*, 2009, vol. 190, p. 538.
568. Loa, I., Grzechnik, A., Schwarz, U., Syassen, K., Han, M., and Kremer, P.K., *J. Alloys Compd.*, 2001, vol. 317–318, p. 103.
569. Świątowska-Mrowiecka, J., Maurice, V., Zanna, S., Klein, L., and Marcus, P., *Electrochim. Acta*, 2007, vol. 52. 5644.
570. Cocciantelli, J.-M., Doumerc, J.-P., Pouchard, M., Broussely, M., Labta, J., *J. Power Sources*, 1991, vol. 34, p. 103.
571. Murphy, D.W., Christian, P.A., Disalvo, F.J., and Waszczak, J.V., *Inorg. Chem.*, 1979, vol. 18, p. 2800.
572. Delmas, C., Cognac-Auradou, H., Cocciantelli, J.M., Ménétrier, M., and Doumerc, J.P., *Solid State Ionics*, 1994, vol. 69, p. 257.
573. Gourier, D., Tranchant, A., Baffier, N., and Messina, R., *Electrochim. Acta*, 1992, vol. 37, p. 2755.
574. Bates, J.B., Dudney, N.J., Lubben, D.C., Gruzalski, G.R., Kwak, B.S., Xiaohua Yu, and Zuhr, R.A., *J. Power Sources*, 1995, vol. 54, p. 58.
575. Navone, C., Baddour-Hadjean, R., Pereira-Ramos, J.P., and Salot, R., *Electrochim. Acta*, 2008, vol. 53, p. 3329.
576. Baddour-Hadjean, R., Navone, C., and Pereira-Ramos, J.P., *Electrochim. Acta*, 2009, vol. 54, p. 6674.
577. Fleutot, B., Martinez, H., Pecquenard, B., Ledeuil, J.B., Levasseur, A., and Gonbeau, D., *J. Power Sources*, 2008, vol. 180, p. 836.
578. McGraw, J.M., Bahn, C.S., Parilla, P.A., Perkins, J.D., Readey, D.W., and Ginley, D.S., *Electrochim. Acta*, 1999, vol. 45, p. 187.
579. Zhang, J.-G., McGraw, J.M., Turner, J., and Ginley, D., *J. Electrochem. Soc.*, 1997, vol. 144, p. 1630.
580. Groult, H., Le Van, K., Mantoux, A., Perrigaud, L., and Doppelt, P., *J. Power Sources*, 2007, vol. 174, p. 312.
581. Lantelme, F., Mantoux, A., Groult, H., and Lincot, D., *J. Electrochem. Soc.*, 2003, vol. 150, p. A1202.
582. Mantoux, A., Groult, H., Balnois, E., Doppelt, P., and Gueroudji, L., *J. Electrochem. Soc.*, 2004, vol. 150, p. A368.
583. Szorenyi, T., Bali, K., and Hevesi, I., *J. Non-Cryst. Solids*, 1980, vol. 35–36, p. 1245.
584. Inumaru, K., Okuhara, T., Misono, M., Matsabayashi, N., Shimada, H., and Nishijima, A., *J. Chem. Soc. Faraday Trans.*, 1992, vol. 88, p. 625.
585. Cohen, Y.S. and Aurbach, D., *Electrochim. Commun.*, 2004, vol. 6, p. 536.
586. Le Van, K., Groult, H., Mantoux, A., Perrigaud, L., Lantelme, F., Lindström, R., Badour-Hadjean, R., Zanna, S., and Lincot, D., *J. Power Sources*, 2006, vol. 160, p. 592.
587. Liu, P., Lee, S.-H., Tracy, C.E., and Turner, J.A., *J. Power Sources*, 2003, vol. 119–121, p. 305.
588. Bae, J.-S. and Pyun, S.-I., *Solid State Ionics*, 1996, vol. 90, p. 251.
589. Potiron, E., Le Gal La Salle, A., Verbaere, A., Piffard, Y., and Guyomard, D., *Electrochim. Acta*, 1999, vol. 45, p. 197.
590. Sato, Y., Nomura, T., Tanaka, H., and Kobayakawa, K., *J. Electrochem. Soc.*, 1991, vol. 138, p. L37.
591. Lee, J.-K., Kim, G.-P., Song, I.K., and Baeck, S.-H., *Electrochim. Commun.*, 2009, vol. 11, p. 1571.
592. Lee, J.-W. and Pyun, S.-I., *J. Power Sources*, 2003, vol. 119–121, p. 760.
593. Świątowska-Mrowiecka, J., Maurice, V., Zanna, S., Klein, L., Briand, E., Vickridge, I., and Marcus, Ph., *J. Power Sources*, 2007, vol. 170, p. 160.
594. Lindström, R., Maurice, V., Groult, H., Perrigaud, L., Zanna, S., Cohen, C., and Marcus, P., *Electrochim. Acta*, 2006, vol. 51, p. 5001.
595. Terukov, E.I., Nikitin, S.E., Nikolaev, Yu.A., Kulova, T.L., and Skundin, A.M., *Tech. Phys. Lett.*, 2009, vol. 35, p. 1111.
596. Park, H.-K. and Smyrl, W.H., *J. Electrochem. Soc.*, 1995, vol. 142, p. 1068.
597. Vivier, V., Farcy, J., and Pereire-Ramos, J.P., *Electrochim. Acta*, 1998, vol. 44, p. 831.
598. Ban, C., Chernova, N.A., and Whittingham, M.S., *Electrochim. Commun.*, 2009, vol. 11, p. 522.
599. Takahashi, K., Limmer, S.J., Wang, Y., and Cao, G., *Jpn. J. Appl. Phys., Part 1*, 2005, vol. 44 B, p. 662.
600. Petkov, V., Zavalij, P.Y., Lutta, S., Whittingham, M.S., Parvanov, V., and Shastri, S., *Phys. Rev. B*, 2004, vol. 69. Article number 085410, 854101.
601. O'Dwyer, C., Lavayen, V., Newcomb, S.B., Benavente, E., Santa Ana, M.A., González, G., and Sotomayor Torres, C.M., *Electrochim. Solid-State Lett.*, 2007, vol. 10, p. A111.
602. Grigor'eva, A.V., Kulova, T.L., Skindin, A.M., Gudilin, E.A., Garshev, A.V., and Tret'yakov, Yu.D., *Al'tern. Energ. Ekol.*, 2008, vol. 64, no. 8, p. 86.
603. Yu, J., Liu, S., Cheng, B., Xiong, J., Yu, Y., and Wang, J., *Mater. Chem. Phys.*, 2006, vol. 95, p. 206.
604. Ng, S.H., Chew, S.Y., Wang, J., Wexler, D., Tournayre, Y., Konstantinov, K., and Liu, H.K., *J. Power Sources*, 2007, vol. 174, p. 1032.
605. Salloux, K., Chaput, F., Wong, H.P., Dunn, B., and Brenner, M.W., *J. Electrochem. Soc.*, 1995, vol. 142, p. L191.
606. Le, D.B., Passerini, S., Guo, J., Ressler, J., Owens, B.B., and Smyrl, W.H., *J. Electrochem. Soc.*, 1996, vol. 143, p. 2099.
607. Owens, B.B., Passerini, S., and Smyrl, W.H., *Electrochim. Acta*, 1999, vol. 45, p. 215.
608. Park, H.-K., Smyrl, W.H., and Ward, M.D., *J. Electrochem. Soc.*, 1995, vol. 142, p. 1068.

609. Coustier, F., Passerini, S., and Smyrl, W.H., *J. Electrochem. Soc.*, 1998, vol. 145, p. L73.
610. Dewan, C. and Teeters, D., *J. Power Sources*, 2003, vol. 119–121, p. 310.
611. Livage, J., *Chem. Mater.*, 1991, vol. 3, p. 578.
612. Livage, J., Baer, N., Pereira-Ramos, J.-P., and Davidson, P., *Mat. Res. Soc. Proc.*, 1995, vol. 369, p. 179.
613. Inagaki, M., Watanabe, T.A., and Shimizu, A., *Solid State Ionics*, 1996, vol. 86–88, p. 853.
614. Semenenko, D.A., Kulova, T.L., Skundin, A.M., Kozlova, M.G., Pomerantseva, E.A., Grigor'eva, A.V., Gudilin, E.A., and Tret'yakov, Yu.D., *Al'tern. Energ. Ekol.*, 2007, vol. 48, no. 4, p. 82.
615. Coustier, F., Hill, J., Owens, B.B., Passerini, S., and Smyrl, W.H., *J. Electrochem. Soc.*, 1999, vol. 146, p. 1355.
616. Choi, J.-H. and Park, H.-K., *Electrochim. Acta*, 2004, vol. 50, p. 405.
617. Coustier, F., Jarero, G., Passerini, S., and Smyrl, W.H., *J. Power Sources*, 1999, vol. 83, p. 9.
618. Wei, Y., Ryu, Ch.-W., and Kim, K.-B., *J. Power Sources*, 2007, vol. 165, p. 386.
619. Park, H.-K., *Solid State Ionics*, 2005, vol. 176, p. 307.
620. Leroux, F., Koene, B.E., and Nazar, L.F., *J. Electrochem. Soc.*, 1996, vol. 143, p. L181.
621. Malta, M., Louarn, G., Errien, N., and Torresi, R.M., *J. Power Sources*, 2006, vol. 156, p. 533.
622. Leroux, F., Goward, G., Power, W.P., and Nazar, L.F., *J. Electrochem. Soc.*, 1997, vol. 144, p. 3886.
623. Kang, S.G., Kim, K.M., and Chang, S.H., *J. Power Sources*, 2004, vol. 133, p. 263.
624. Park, N.G., Ryu, K.S., and Chang, S.H., *J. Power Sources*, 2002, vol. 103, p. 273.
625. Ferreira, M., Zucolotto, V., Huguenin, F., Torresi, R.M., and Oliveira, O.N., Jr., *J. Nanosci. Nanotechnol.*, 2002, vol. 2, p. 29.
626. Huguenin, F., Torresi, R.M., and Buttry, D.A., *J. Electrochem. Soc.*, 2002, vol. 149, p. A546.
627. Goward, G.R., Leroux, F., and Nazar, L.F., *Electrochim. Acta*, 1998, vol. 43, p. 1307.
628. Harreld, J., Wong, H.P., Dave, B.C., Dunn, B., and Nazar, L.F., *J. Non-Cryst. Solids*, 1998, vol. 225, p. 319.
629. Boyano, I., Bengoechea, M., de Meatza, I., Miguel, O., Cantero, I., Ochoteco, E., Grande, H., Lira-Cantú, M., and Gomez-Romero, P., *J. Power Sources*, 2007, vol. 174, p. 1206.
630. Huguenin, F., Girotto, E.M., Torresi, R.M., and Buttry, D.A., *J. Electroanal. Chem.*, 2002, vol. 536, p. 37.
631. Demetz, G.F., Anaissi, F.J., and Toma, H.E., *Electrochim. Acta*, 2000, vol. 46, p. 547.
632. Subba Reddy, Ch.V., Wei, J., Zhu, Q.-Y., Zhi-Rong, D., Chen, W., Sun-il Mho, and Kalluru, R.R., *J. Power Sources*, 2007, vol. 166, p. 244.
633. Subba Reddy, Ch.V., Jin, A.-P., Han, X., Zhu, Q.-Y., Mai, L.-Q., and Chen, W., *Electrochim. Commun.*, 2006, vol. 8, p. 279.
634. Ugaji, M., Ibino, M., and Kudo, T., *J. Electrochem. Soc.*, 1995, vol. 142, p. 3664.
635. Panero, S., Pasquali, M., and Pistoia, G., *J. Electrochem. Soc.*, 1983, vol. 130, p. 1225.
636. Dai, J., Li, S.F.Y., Gao, Zh., and Siow, K.S., *J. Electrochem. Soc.*, 1998, vol. 145, p. 3057.
637. Kannan, A.M. and Manthiram, A., *J. Power Sources*, 2006, vol. 159, p. 1405.
638. Yu, A., Kumagai, N., Liu, Zh., and Lee, J.Y., *J. Power Sources*, 1998, vol. 74, p. 117.
639. Jouanneau, S., Le Gal La Salle, A., Verbaere, A., and Guyomard, D., *J. Electrochem. Soc.*, 2005, vol. 152, p. A1660.
640. Manev, V., Momchilov, A., Nassalevska, A., Pistoia, G., Pasquali, M., *J. Power Sources*, 1995, vol. 54, p. 501.
641. de Picciotto, L.A., Adendorff, K.T., Liles, D.C., and Thackeray, M.M., *Solid State Ionics*, 1993, vol. 62, p. 297.
642. Nassau, K. and Murphy, D.W., *J. Non-Cryst. Solids*, 1981, vol. 44, p. 297.
643. Xie, J., Li, J., Zhan H., and Zhou, Y., *Mater. Lett.*, 2003, vol. 57, p. 2682.
644. Geronov, Y., Puresheva, B., Moshtev, R.V., Zlatilova, P., Kosev, T., Stoynov, Z., Pistoia, G., and Pasquali, M., *J. Electrochem. Soc.*, 1990, vol. 137, p. 3338.
645. Kawakita, J., Katayama, Y., Miura T., and Kishi, T., *Solid State Ionics*, 1998, vol. 107, p. 145.
646. Fu, L., Liu, H., Li, C., Wu, Y., Rahm, E., Holze, R., and Wu, H., *Prog. Mater. Sci.*, 2005, vol. 50, p. 881.
647. Pistoia, G., Pasquali, M., Wang, G., and Li, L., *J. Electrochem. Soc.*, 1990, vol. 137, p. 2365.
648. Yang, G., Wang, G., and Hou, W.H., *J. Phys. Chem.*, 2005, vol. B 109, p. 11186.
649. Wu, F., Wang, L., Wu, Ch., and Bai, Y., *Electrochim. Acta*, 2009, vol. 54, p. 4613.
650. Feng, Y., Hou, F., and Li, Y.L., *J. Power Sources*, 2009, vol. 192, p. 708.
651. Liu, Q.Y., Liu, H.W., Zhou, X.W., Cong, C.J., and Zhang, K.L., *Solid State Ionics*, 2005, vol. 176, p. 1549.
652. Brylev, O.A., Shlyakhtin, O.A., Egorov, A.V., and Tretyakov, Y.D., *J. Power Sources*, 2007, vol. 164, p. 868.
653. Kawakita, J., Kato, T., Katayama, Y., Miura, T., and Kishi, T., *J. Power Sources*, 1999, vol. 81–82, p. 448.
654. Pistoia, G., Pasquali, M., Geronov, Y., Manev, V., and Moshtev, R.V., *J. Power Sources*, 1989, vol. 27, p. 35.
655. Liu, Y., Zhou, X., and Guo, Y., *J. Power Sources*, 2008, vol. 184, p. 303.
656. Jouanneau, S., Verbaere, A., Lascaud, S., and Guyomard, D., *Solid State Ionics*, 2006, vol. 177, p. 311.
657. Shi, Q., Hu, R., Ouyang, L., Zeng, M., and Zhu, M., *Electrochim. Commun.*, 2009, vol. 11, p. 2169.
658. Xu, H.Y., Wang, H., Song, Zh.Q., Wang, Y.W., Yan, H., and Yoshimura, M., *Electrochim. Acta*, 2004, vol. 49, p. 349.
659. Tran, N., Bramnik, K.G., Hibst, H., Prölß, J., Mronga, N., Holzapfel, M., Scheifele, W., and Novák, P., *J. Electrochem. Soc.*, 2008, vol. 155, p. A384.
660. Patey, T.J., Ng, S.H., Büchel, R., Tran, N., Krumeich, F., Wang, J., Liu, H.K., and Novák, P., *Electrochim. Solid-State Lett.*, 2008, vol. 11, p. A46.

661. Liu, H., Yang, H., and Huang, T., *Mater. Sci. Eng., B*, 2007, vol. 143, p. 60.
662. West, K., Zachau-Christiansen, B., Skaarup, S., Saidi, Y., Barker, J., Olsen, I.I., Pynenburg, R., and Koksbang, R., *J. Electrochem. Soc.*, 1996, vol. 143, p. 820.
663. Tanguy, F., Gaubicher, J., Soudan, P., Bourgeon-Martin, N., Mauchamp, V., and Guyomard, D., *Electrochim. Solid-State Lett.*, 2007, vol. 10, p. A184.
664. Zhao, M., Jiao, L., Yuan, H., Feng, Y., and Zhang, M., *Solid State Ionics*, 2007, vol. 178, p. 387.
665. Liu, Y., Zhou, X., and Guo, Y., *Electrochim. Acta*, 2009, vol. 54, p. 3184.
666. Feng, C.Q., Huang, L.F., Guo, Z.P., Wang, J.Z., and Liu, H.K., *J. Power Sources*, 2007, vol. 174, p. 548.
667. Huang, H., Yin, S.-C., Kerr, T., Taylor, N., and Nazar, L.F., *Adv. Mater.*, 2002, vol. 14, p. 1525.
668. Saïdi, M.Y., Barker, J., Huang, H., Swoyer, J.L., and Adamson, G., *Electrochim. Solid-State Lett.*, 2002, vol. 5, p. A149.
669. Saïdi, M.Y., Barker, J., Huang, H., Swoyer, J.L., and Adamson, G., *J. Power Sources*, 2003, vol. 119–121, p. 266.
670. Yin, S.-C., Strobel, P.S., Grondéy, H., and Nazar, L.F., *Chem. Mater.*, 2004, vol. 16, p. 1456.
671. Li, Y., Zhou, Zh., Ren, M., Gao, X., and Yan, J., *Electrochim. Acta*, 2006, vol. 51, p. 6498.
672. Fu, P., Zhao, Y., Dong, Y., An, X., and Shen, G., *Electrochim. Acta*, 2006, vol. 52, p. 1003.
673. Fu, P., Zhao, Y., An, X., Dong, Y., and Hou, X., *Electrochim. Acta*, 2007, vol. 52, p. 5281.
674. Gaubicher, J., Wurm, C., Goward, G., Masquelier, C., and Nazar, L., *Chem. Mater.*, 2000, vol. 12, p. 3240.
675. Morgan, D., Ceder, G., Saïdi, M.Y., Barker, J., Swoyer, J., Huang, H., and Adamson, G., *Chem. Mater.*, 2002, vol. 14, p. 4684.
676. Yin, S.-C., Grondéy, H., Strobel, P., Anne, M., and Nazar, L.F., *J. Am. Chem. Soc.*, 2003, vol. 125, p. 10402.
677. Chen, Q., Wang, J., Tang, Zh., He, W., Shao, H., and Zhang, J., *Electrochim. Acta*, 2007, vol. 52, p. 5251.
678. Li, Y., Liu, X., and Yan, J., *Electrochim. Acta*, 2007, vol. 53, p. 474.
679. Chang, C., Xiang, J., Shi, X., Han, X., Yuan, L., and Sun, J., *Electrochim. Acta*, 2008, vol. 54, p. 623.
680. Zhou, X., Liu, Y., and Guo, Y., *Electrochim. Acta*, 2009, vol. 54, p. 2253.
681. Patoux, S., Wurm, C., Morcrette, M., Rousse, G., and Masquelier, C., *J. Power Sources*, 2003, vol. 119–121, p. 278.
682. Barker, J., Saidi, M.Y., and Swoyer, J.L., *J. Electrochem. Soc.*, 2003, vol. 150, p. A684.
683. Rui, X.H., Li, C., and Chen, C.H., *Electrochim. Acta*, 2009, vol. 54, p. 3374.
684. Wang, J., Liu, J., Yang, G., Zhang, X., Yan, X., Pan, X., and Wang, R., *Electrochim. Acta*, 2009, vol. 54, p. 6451.
685. Wang, L., Zhang, L.-C., Lieberwirth, I., Xu, H.-W., Chen, Ch.-H., *Electrochim. Commun.*, 2010, vol. 12, p. 52.
686. Ren, M., Zhou, Zh., Li, Y., Gao, X.P., and Yan, J., *J. Power Sources*, 2006, vol. 162, p. 1357.
687. Chen, Y., Zhao, Y., An, X., Liu, J., Dong, Y., and Chen, L., *Electrochim. Acta*, 2009, vol. 54, p. 5844.
688. He, Y.-B., Tang, Zh.-Y., Song, Q.-Sh., Xie, H., Yang, Q.-H., Liu, Y.-G., and Ling, G.-W., *J. Power Sources*, 2008, vol. 185, p. 526.
689. Hashem, A.M.A., Abdel-Ghany, A.E., Eid, A.E., Trottier, J., Zaghib, K., Mauger, A., and Julien, C.M., *J. Power Sources*, 2011, vol. 196, p. 8632.
690. Kang, K., Meng, Y.Sh., Bréger, J., Grey, C.P., and Ceder, G., *Science*, February 17, 2006, p. 977.
691. Santhanam, R. and Rambabu, B., *J. Power Sources*, 2010, vol. 195, p. 5442.
692. Rabanal, M.E., Gutierrez, M.C., Garcia-Alvarado, F., Gonzalo, E.C., and Arroyo-de, D.M.E., *J. Power Sources*, 2006, vol. 160, p. 523.
693. Wang, F., Yang, J., NuLi, Y., and Wang, J., *J. Power Sources*, 2011, vol. 196, p. 4806.
694. Reddy, M.V., Subba Rao, G.V., and Chowdari, B.V.R., *J. Power Sources*, 2010, vol. 195, p. 5768.
695. Shigeto, O., Mizuki, U., Yasushi, U., and Jun-ichi, Y., *J. Power Sources*, 2005, vol. 146, p. 565.
696. Khasanova, N.R., Gavrilov, A.N., Antipov, E.V., Bramnik, K.G., and Hibst, H., *J. Power Sources*, 2011, vol. 196, p. 355.